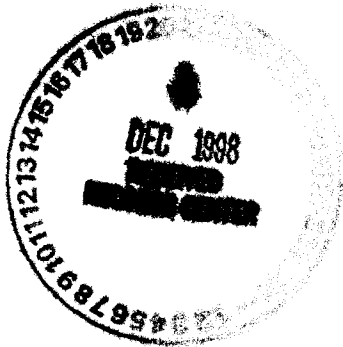


NOTICE

All drawings located at the end of the document.



RF/RMRS-98-285.UN

PRELIMINARY REPORT ON SOIL
EROSION/SURFACE WATER
SEDIMENT TRANSPORT MODELING
FOR THE ACTINIDE MIGRATION
STUDY AT THE ROCKY FLATS
ENVIRONMENTAL TECHNOLOGY
SITE

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*Preliminary Report on Soil Erosion/Surface Water Sediment
Transport Modeling for the Actinide Migration Study at the RFETS*

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1.0 INTRODUCTION

1.1 Purpose

This preliminary report presents an overview of fiscal year (FY) 1998 Actinide Migration Studies (AMS) watershed soil erosion and surface water sediment transport modeling project activities. The goal of the modeling project is to estimate and quantify actinide loading rates to surface water. This report includes:

- A summary of soil erosion processes;
- A description of the WEPP watershed model and input parameters;
- A review of FY-98 activities which provided data for calibration of the model; and
- The model structure and input parameters for the South Interceptor Ditch (SID) and preliminary calibration results.

The AMS is investigating the mobility of plutonium-239/240 (Pu-239/240), americium-241 (Am-241), and uranium-234, 235, 238 isotopes (U) in the Site environment. The goal of the AMS is to answer the following four questions contained in the AMS Data Quality Objectives (DQO) document (RMRS, 1998a):

1. Urgent: What are the important actinide sources and migration processes that account for recent monitoring results greater than the surface water quality standards?
2. Near-Term: What will be the impacts of actinide migration on planned remedial actions? To what level do sources need to be cleaned up to protect surface water from exceeding action levels for actinides?
3. Long-Term: How will actinide migration affect surface water quality after Site closure? In other words, will soil action levels be sufficiently protective of surface water over the long-term?
4. Long-Term: What is the long-term off-Site actinide migration, and how will it impact downstream areas (e.g. accumulation)?

The answers to these questions are needed to determine the clean-up levels for actinides in soils at RFETS that will be protective of surface-water quality in both the short- and long-term. This document reports the preliminary watershed erosion modeling results that will be used for calibrating the soil erosion/surface water transport modeling effort for the Woman and Walnut Creek watersheds in FY 1999.

1.2 Conceptual Model for Surface-Transport of Actinides at RFETS

A Site conceptual model has been assembled to provide both a qualitative understanding of actinide (herein considered as Pu-239/240, Am-241, and U) sources and transport pathways for the Walnut and Woman Creek watersheds, and to provide a framework for quantifying the transport rates for Site environmental conditions. Current information on the transport of Pu-239/240 and Am-241 in the REFTS environment indicates that actinide transport in sediments by overland flow (soil erosion), and as sediment load in channeled surface water, is a major transport mechanism. These sources potentially contribute to exceedances of Rocky Flats Cleanup Agreement (RFCA) surface-water standards in both the short- and long-term.

1.2.1 The Surface-Water Transport Pathway

The goal of the AMS is to understand and quantify actinide transport processes in order to facilitate the long-term protection of community surface water quality, overall environmental quality, and human health. The major process that leads to the transport of soil particulates to surface-water channels is erosion and overland flow. Channel flow then transports the eroded sediments down stream. Both physical and chemical transport mechanisms can be involved in transport by overland flow, although the physical processes dominate. The watershed erosion modeling project will provide information to quantify the transport rates for overland and channel flow.

1.2.2 Overland Flow and Erosion

Soils are subject to erosive processes that have the potential for transporting actinide-contaminated soil to the Site surface water channels leading to exceedances of the surface water standards and potential transport off-Site. The Site receives an annual average of 368 millimeters (mm) (14.5 inches) of precipitation, with about 50 percent in the form of rain (DOE, 1995a). Precipitation provides the energy of raindrop impact to loosen soil particles from the soil surface. Rainfall runs off when the infiltration capacity of the surface soil is reached, creating overland flow. Snowmelt runs off more slowly than rain, however, if the soil surface is frozen greater amounts of runoff may occur. Rain and snow together provide a means for the potential transport of actinide-contaminated soil across the Site landscape by overland flow and erosive mechanisms.

There are two basic forms of overland flow, inter-rill sheet flow, and concentrated rill flow. A rill is an area on the soil surface that supports concentrated flow; a rill can be thought of as a very small channel. Concentrated rill flow is the flow of runoff in these micro-channels. Much of the erosion that occurs in rills is due to the energy of the flowing water. Inter-rill sheet flow occurs between rills with water running over the soil surface in diffuse or sheet flow. Erosion due to sheet flow is less

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obvious. Much of the energy for detachment of soil particles for transport by inter-rill sheet flow comes from raindrop impact.

Runoff from impervious Industrial Area (IA) surfaces occurs rapidly, but Buffer Zone runoff occurs chiefly on roads, steep hillslopes, and areas where culverts feed IA runoff to the Buffer Zone. Although much of the overland flow in the Buffer Zone originates from this impervious surface drainage, precipitation events greater than about 127 mm (0.5 inches) per 24 hours do produce runoff (EG&G, 1993a and 1993b). The runoff carries particulates, colloids, and small amounts of dissolved constituents down-slope to areas of deposition and to stream channels. The transported sediments can then be carried by channeled flow as suspended solids to quiescent catchments, such as the A-, B- and C-Series Ponds, where larger particles can settle out, or further downstream and potentially off-Site.

Vegetative soil cover and soil characteristics, such as, hydraulic conductivity (rate of infiltration), particle size, and the degree and stability of soil aggregation into secondary particles of larger size control the susceptibility of the soil to erosion. Dense vegetation in many areas of the Walnut and Woman Creek watersheds provides protection against erosion. Small areas with less cover are interspersed throughout the watersheds. These areas and unpaved roads may account for most of the soil erosion that occurs at the Site. Hydraulic conductivity and rainfall simulation studies at the Site have found infiltration to be rapid (DOE, 1995b, Fedors and Warner, 1993, Ryan et al., 1998, and Litaor et al., 1996 and 1998). Recent AMS research on the particle-size distribution of water-stable aggregates in soils from the Walnut and Woman Creek watersheds has shown the Site soils to be stable with the majority of the soils comprised of water stable aggregates greater than 200 microns (0.2 mm or 0.008 inches) in diameter (RMRS, 1998c). This information suggests that erosion rates for Site soils are low. However, a better understanding of erosive processes on the Site is important because small amounts of actinide-contaminated sediments reaching the Site surface water channels may have a significant impact on water quality.

1.2.3 Channel Flow

Surface water channel flow can transport particulates, colloids, and dissolved species. Actinides may be associated with all of these phases. Precipitation events and batch releases from the detention ponds can cause turbulent flows capable of resuspending and transporting stream bed sediments off-Site. Wind can resuspend pond bottom sediments via wave action. Seasonal inversions of pond waters due to temperature differentials have also been documented in Site detention ponds, which temporarily increase concentrations of several water quality constituents (EG&G, 1993c and DOE, 1996). Fish, reptiles, waterfowl, and aquatic mammals also can cause particulate resuspension.

Factors that effect particulate mobility in surface water include:

- In-stream vegetation, such as cattails, that can physically filter the contaminated particulates;

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- Diversion dams or other physical barriers that slow surface flow and enhance particle settling;
- Ice cover on ponds that prevents the resuspension of pond bottom sediments via wave action;
and
- Hydraulic efficiency of the stream channels (e.g. slope, pool to riffle ratio, meandering, etc.).

Particulate transport occurs through combinations of the above processes and not by any single mechanism. The dominant transport pathways and processes determine data needs for modeling. The transport of soil by erosion and overland flow is being modeled using the Watershed Erosion Prediction Project (WEPP) model. The AMS is currently investigating surface water transport models for predicting sediment movement within Site drainage channels. The most efficient method for assessing contributions of soils and sediments to surface water loads of actinides is through the use of models. The current work is limited to consideration of transport in and by water.

2.0 SCOPE

The WEPP Hillslope Profile and Watershed Model was chosen to estimate the quantities of sediments transported to, and by, surface water via environmental pathways, including:

- Runoff / Diffuse Overland Flow; and
- Surface Water Flow (Channeled).

The AMS group is using the WEPP Model to estimate sediment loading to channels within the Walnut and Woman Creek Watersheds, however, the model may not be sufficient to estimate the downstream movement of sediments within the channels (as discussed below in Section 7). If it is determined that the WEPP Model channel flow component is not sufficient, the sediment loading results will be coupled with a yet to be determined surface-water transport model (e.g. HEC-6, OTIS/OTEC, etc) to estimate sediment movement within the watershed channels. The activities and amounts of Pu-239/240 and Am-241 associated with the sediments will be estimated based on data defining the spatial distribution and detailing actinide associations with soil particle sizes and phases. The results will be used to estimate the effects on surface-water quality for the present Site configuration and for selected potential future configurations in order to address the four goals stated in Section 1. Estimates of erosion and sediment movement within the watersheds will be made for periods of up to 1,000 years.

The current document reports the preliminary results for the SID watershed, which drains into Pond C-2 (Figure 1). The results of this year's work will be used to calibrate the model for the remainder of the Woman Creek and Walnut Creek watersheds.

2.1 The Model

The WEPP Watershed Erosion Model, developed by the United States Department of Agriculture (USDA), Agricultural Research Service (ARS), and the United States Department of the Interior and other cooperators, is a new generation of process-oriented, computer-implemented erosion prediction technology, based on modern hydrologic and erosion science (Flanagan and Nearing, 1995). The WEPP model is a distributed parameter, continuous simulation computer program which predicts: 1) soil loss and sediment deposition from overland flow on hillslopes, (2) sediment deposition in impoundments, and (3) sediment loss and deposition in concentrated flow in small channels. Extensive model validation has been done by ARS and other cooperators (Zang et al., 1996, Flanagan and Nearing, 1995, Baffaut et al. 1998).

Major model input files include:

- Climate data, including daily precipitation amounts and intensities, temperate, wind speed and direction, solar radiation, and dew point;
- Hillslope data, including slope length, shape, steepness and orientation;
- Soil data, including soil characteristics such as texture, hydraulic conductivity; organic content, and soil erodibility parameters;
- Cropping/management data, including plant types, growth parameters, and residue decomposition parameters;
- Channel/impoundment data, including the shape, length, steepness, bed composition and hydraulics, and outlet structures, if present.

Continuous simulations can be run over a period of up to 999 years. Rain can occur on any given day and may or may not cause a runoff event. If runoff occurs, soil loss, sediment deposition, sediment delivery off the hillslope, and the sediment surface area enrichment ratio for the event are estimated.

2.1.1 Model Components

The model also includes components for: (1) stochastic weather generation; (2) winter processes; (3) overland flow hydraulics to estimate runoff; (3) soil erosion and deposition, estimated using raindrop impact, inter-rill sheet flow, and concentrated rill flow; (4) daily water balance; (5) plant growth; (6) residue decomposition; (7) soil response to environmental factors; and (8) a channel component to estimate flow and sediment transport for ephemeral flow drainages with areas up to about 60 square kilometers (km²) (23.2 square miles).

Climate The climate generator, CLIGEN, estimates daily values for rainfall amounts and durations, maximum intensities, times to peak intensity, maximum and minimum temperatures, solar radiation, wind speed and direction, and dew point using local meteorological data, or actual Site precipitation data can be used. CLIGEN uses a single-peak storm pattern but can also accept breakpoint rainfall data. The winter processes component estimates soil frost, soil thaw, snowfall and snowmelt. Estimated values for solar radiation, air temperature, and wind drive the snow melting process.

Plant Growth For rangelands, plant growth, and the aggregate above and below ground biomass, are simulated for the entire plant community, based on the ERHYM-II (White, 1987) and SPUR models (Wight and Skiles, 1987) and are based on a potential growth curve. Initiation of growth in the spring is dependent on temperature and moisture. The plant growth component also includes routines to estimate plant residue decomposition as dependent on temperature and precipitation.

Overland Flow The hydrology component, computes infiltration, runoff, soil evaporation, plant transpiration, soil water percolation, plant and residue rainfall interception, depressional storage, and subsurface tile drainage. The infiltration routine uses the modified Green and Ampt (Mein and Larson, 1973 and Chu 1978) infiltration equation. Runoff is computed using the kinematic wave equations or an approximation of the kinematic wave solutions (Stone et al. 1995) obtained for a range of rainfall intensity distributions, hydraulic roughness, and infiltration parameter values. The overland flow hydraulics component, computes the impacts of soil roughness, residue cover, plant cover on runoff rates, flow shear stress, and flow sediment transport capacity on soil erosion from the hillslope. Water balance routines are modifications of the Simulator for Water Resource in Rural Basins (SWRRB) water balance (Williams et al. 1985).

A steady-state sediment continuity equation estimates the change in sediment load in the flow with distance downslope. Soil detachment in interrill areas is a function of the rainfall intensity and runoff rate. Delivery of sediment to rills is a function of slope and surface roughness. Detachment in rills occurs if hydraulic shear stress exceeds the critical value, and sediment in the flow is less than the flow's capacity. Deposition occurs on a hillslope when the sediment load in the flow is greater than the capacity of the flow to transport it. Soil detachment is adjusted by the effects of canopy cover, ground cover, and buried residue. The model estimates the selective deposition of different sediment size classes, the sediment size distribution leaving the hillslope, and the sediment specific surface enrichment ratio. The watershed simulations use three more components: the channel hydrology and hydraulics, channel erosion, and impoundment components.

The channel hydrology component computes infiltration, soil evaporation, plant transpiration, soil water percolation, rainfall interception, and depression storage and soil drainage in the same way as the hillslope component. Excess rainfall is then combined with runoff from hillslopes, channels, or impoundments. Transmission losses in the channels are computed using a modified Green-Ampt infiltration formula. Runoff peaks are computed using either the Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) peak method (an empirical formula that is a function of the volume of runoff, contributing area and slope, and time of concentration) (Knisel, 1980), or a modified form of the rational model used in Erosion-Productivity Impact Calculator (EPIC) (Williams, 1995).

The channel erosion component predicts detachment and deposition in channels. Detachment occurs at a critical shear stress that is dependent on the bed materials and characteristics, and if the incoming sediment load is less than the transport capacity of the channel. When the sediment load is greater than the transport capacity deposition occurs. The particle size distribution of the sediment leaving the channel and the enrichment ratio are also estimated.

The impoundment routine routes runoff and sediment through an impoundment (terraces, ponds, check dams, filter fences, and culverts) and determines the total amount of runoff leaving the

structure, sediment deposited within the structure, and the amount and size of the sediment leaving the structure. This routine was designed for testing various types of structures to limit sediment movement. Up to 10 impoundments may be simulated for a watershed. A wide variety of geometries and outflow structures can be specified. Deposition in the impoundment is calculated assuming complete mixing and then adjusted to account for stratification, non-homogenous concentrations, and the shape of the impoundment. A continuity mass balance equation is used to predict outflow concentrations, assuming complete mixing.

2.1.2 Model Output

The output from the WEPP Model includes runoff and erosion summaries, by storm, month, annual or average annual periods, average annual sediment delivery from the hillslope, particle size distributions of the detached sediment and sediment leaving the hillside, and an estimate of the enrichment of the specific surface area of the sediment. This output contains time-integrated estimates of runoff, erosion, sediment delivery, sediment enrichment, and spatial distribution of erosion on the hillslopes. Output is also available for plant and soil parameters for the duration of the simulation. The watershed component produces erosion and runoff data for entire watershed. The model was designed to assist in resource conservation decisions and in determining impacts of sediment-borne constituents reaching the waterways.

3.0 STUDY AREA

Three drainage basins collect surface water at RFETS (Figure 1). The basins are drained by natural, intermittent to ephemeral, and perennial streams that generally flow from west to east. The northwest portion of the Site is drained by Rock Creek, which flows into Coal Creek east of the Site. This drainage is not considered to have been affected by Site activities and will not be included in this study. Walnut Creek drains the northeast quadrant of the Site, and Woman Creek collects water from the southern portion of the Buffer Zone. The soil erosion/surface water sediment transport study area includes both of these watersheds, which are described below.

The on-Site portion of the Woman Creek watershed is approximately 8 km² (3.1 square miles). Woman Creek is formed by two branches to the west, known as the northwest and southwest branches. These branches converge to the west of the Original Landfill. There are two detention ponds in the Woman Creek drainage: (1) Pond C-1, which is located within the stream channel and is presently configured for continuous flow-through; and (2) Pond C-2; which is off-channel and used to collect runoff from the south side of the IA, the 881 Hillside, and the 903 Pad Lip Area via the SID. Pond C-2 is batch discharged to Woman Creek. In the past, the majority of water from Woman Creek was diverted into Mower Ditch. The diversion is currently shutoff, and water flows in the natural channel off-Site to Woman Creek Reservoir.

The SID was constructed in 1979 to divert surface water runoff from the southern portion of the IA to Pond C-2 (Figure 1). It was originally designed to handle a 100-year precipitation event. Erosion, sedimentation, and encroachment of vegetation have reduced the SID's flow velocity and capacity. The SID was selected for preliminary modeling and calibration purposes due to its relatively small size, the proximity of the 903 Pad, and poorly documented data indicating that actinide contamination in the watershed may be mobile under high rainfall conditions.

The Walnut Creek watershed is about 3.7 square miles (2,300 acres) in area (Figure 1). The watershed is comprised of two perennial streams: South Walnut Creek and North Walnut Creek, and ephemeral to intermittent features known as No Name Gulch and the McKay Bypass Canal. South Walnut Creek receives runoff from the IA, including the Central Avenue Ditch and the 903 Pad Area. The natural channel has been greatly changed by construction in the IA and the B-Series Detention Ponds (Figure 1). Ponds B-1 and B-2 are normally off-line, but maintained at a level to keep sediments wet and for IA spill control. Water in Pond B-3 is batch discharged to B-4, then flows through to B-5, which is currently pumped to Pond A-4 in North Walnut Creek. A gate valve and stand pipe are installed in Pond B-5 that allow for potential direct batch releases in the future.

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Water in the upper reaches of North Walnut Creek, to the northwest of the IA, is diverted to the McKay Bypass; flowing to the north of the Present Landfill and eventually re-entering the Walnut Creek drainage downstream of No Name Gulch. Water draining from the north side of the IA, enters North Walnut Creek, and is diverted by pipeline around Ponds A-1 and A-2 into A-3. Ponds A-1 and A-2 are used for spill control and do not discharge into the drainage. Pond A-3 is batch released to Pond A-4, which is batch discharged into the North Walnut Creek channel.

The Present Landfill and the Landfill Pond are situated in the headwaters of No Name Gulch. The Landfill Pond does not discharge into the gulch. Flows in No Name Gulch result primarily from base-flow runoff from surrounding hillsides.

The soil erosion/surface water transport modeling study will include all areas drained by the Woman and Walnut Creek Watersheds. For FY 1998, the SID drainage (contained in the Woman Creek Watershed) has been used for initial calibration of the model. Modeling efforts will then move to Walnut Creek to provide information to address recent surface water monitoring results above the surface water standards and the urgent question as stated in the Purpose section. The Woman Creek Watershed will also be modeled, including the SID. These activities will provide information to evaluate actinide cleanup levels for the 903 Pad Area and other areas with actinide-contaminated surface soils. The study area is limited to the RFETS, but estimates of actinide loading to off-Site watershed reaches will be made in order to assess potential downstream impacts.

4.0 WEPP CALIBRATION ACTIVITIES IN FISCAL YEAR 1998

Several activities were undertaken in FY 98 to provide data for calibration of the watershed model to Site conditions, including:

- Soil and sediment sampling (RMRS, 1998c);
- Actinide distribution on soil aggregates and aggregate characterization (RMRS, 1998c);
- Actinide loading analysis for Walnut and Woman Creeks (RMRS, 1998b);
- Spatial analysis of Pu-239/240 and Am-241 distributions in surface soils; and
- Surface water monitoring in rangeland sub-basins.

These activities are discussed briefly in the following sections.

4.1 Actinide Distribution on Soil Aggregates and Aggregate Characterization

The WEPP model predicts the particle size distribution of particles that are eroded from hillslopes and entrained in surface runoff. As discussed in Section 4.1.1, 15 surface soil and three sediment samples collected in FY 98 were analyzed to determine the size distribution of water-stable aggregates and the distribution of Am-241 and Pu-239/240 among them. How chemical and physical processes can change the particle-size distribution of the aggregates by disintegrating the materials that bind small soil particles to form larger aggregates is also being evaluated, and is discussed in Section 4.1.2.

4.1.1 Aggregate Stability and Am-241-Pu-239/240 Distribution in Surface Soils and Sediments

In FY 1998, data for Pu-239/240 and Am-241 activity in 65 surface soil samples from the Walnut Creek and Woman Creek watersheds were acquired as part of the *Plan for Source Evaluation and Preliminary Actions for Walnut Creek Water-Quality Results* as required by the *Rocky Flats Cleanup Agreement* (RFCA). Samples collected at 18 selected locations were also fractionated by wet sieving and column settling analysis to determine the relative percentages of sand, silt, and clay-sized (<0.2 mm, <0.01 mm, and <0.002 mm respectively) water-stable aggregates in the samples. Fifteen of these sampling locations are soil-sampling locations, and three are sediment sampling locations from Walnut Creek. The size fractions were chosen to be consistent with the WEPP model erosion output. Each size fraction was analyzed for Pu-239/240 and Am-241 to obtain data on the distribution of Pu-239/240 and Am-241 in the water-stable aggregates.

Soil activity and particle size distribution data were collected to answer the following questions:

- What is the total Pu-239/240 and Am-241 activity in the top 5 centimeters (cm) of Site soils and in Walnut Creek bed sediments?
- What is the total organic carbon content of the Site soils and Walnut Creek bed sediments?
- What is the distribution of water-stable aggregate sizes in Site soils and Walnut Creek bed sediments?

4.1.2 Aggregate Composition and Am-241-Pu-239/240 Particle-Size Relationships

The United States Environmental Protection Agency (USEPA) provided a grant to the Colorado School of Mines (CSM) to study characteristics of soil aggregation and the fate of associated Pu-239/240 and Am-241. Ten surface soil samples were collected from the drainage area above the new gaging station, GS42 (Appendix Figure B-1), under supervision of the investigating scientists. CSM is measuring the particle size distribution and actinide content of aggregates that are dispersed by various chemical and physical means for comparison to results obtained for water-stable aggregates. The study will provide useful information for modeling potential future Site conditions and extreme events (e.g. fires, floods, etc.) with the WEPP model. The results may also lend insight to the fate of eroded sediments whose ultimate fate is deep-water burial, aeolian transport, wetland entrapment, and other environmental fates.

Knowledge of the composition of the aggregate-binding materials will create understanding of the potential conditions that could break down the aggregates into smaller, and presumably more mobile particle sizes. It will also further understanding of the distribution of Pu-239/240 and Am-241 among primary particles, increase Site knowledge of the effect of aggregate disintegration on the fate of the actinides, and increase understanding of actinide mobility under different chemical and physical conditions of the surface soils.

4.2 Spatial Analysis of Pu-239/240 and Am-241 Distributions in Surface Soils

All analytical results from currently available Pu-239/240, Am-241, and U isotope surface soil samples taken at RFETS were analyzed using geostatistical techniques, in order to better predict actinide surface-soil activities for use with the WEPP model. The purpose of this work was to evaluate historical data available from the Site and new results from sampling conducted in the Spring of 1998, which enhanced the existing Site data from previous sampling work. This preliminary report focuses on Pu-239/240 and its spatial distribution across RFETS. The methods developed for Pu-239/240 will then be applied to Am-241 and U isotopes next FY. A discussion of the methodology for determining the spatial distributions and the results are presented in Appendix A.

4.3 Surface Water Monitoring in Rangeland Sub-Basins

The AMS installed two continuously-recording stream gaging stations equipped with automatic water samplers in two small, rangeland sub-basins to measure runoff and sediment transport for WEPP Model calibration. Gaging stations are shown in Appendix B, Figure B-1. One station (GS41) is located in a small ephemeral watershed that is tributary to the south bank of Walnut Creek, just upstream from the flume pond above gaging station GS03. The other station (GS42) is on the eastern-most ephemeral tributary to the South Interceptor Ditch. Each station uses a flume and continuously recording flow meter to measure stream discharge. The flow meters trigger the automatic water samplers to collect a composite water sample based on flow. The samples will be analyzed for total suspended solids (TSS), Pu-239/240, Am-241, and particle size distribution. No flow has been recorded to date. Flow is expected under normal spring precipitation conditions, and it is hoped data will become available in the second quarter of FY 1999. Funding for the monitoring equipment and chemical analyses was provided by the USEPA, Region VIII.

4.4 Actinide Loading Analysis

Available surface water discharge and actinide activity data from Site monitoring programs were compiled to compute actinide loads on a storm-specific and annual basis. The loading analysis was done for Site watershed sub-basins, which are coincident with locations of stream gaging and runoff sampling stations (RMRS, 1998b).

Comparison of the loading and yield results to the WEPP model output will allow calibration of the model-input data to appropriately simulate Site conditions. For example, the WEPP watershed model output includes the quantity of sediment that leaves the outlet of a channel on an annual basis, and the Actinide Loading Analysis (RMRS, 1998b) includes estimates for the annual TSS yields to serve as target results for the WEPP model.

The runoff coefficient is a hydrologic parameter for predicting storm runoff using the Rational Method (Dunne and Leopold, 1978). The runoff coefficient describes the percentage of precipitation that will run off of a drainage basin as surface water. Estimated runoff coefficients will be used to calibrate the hydrologic components of the WEPP model. A summary of the results from the loading analysis is provided in Appendix B.

5.0 DATA SOURCES AND MODEL STRUCTURE FOR THE SOUTH INTERCEPTOR DITCH

Data for this modeling effort come from Site monitoring and remediation programs, U. S. Geological Survey publications, U. S. Soil Conservation Service Soil Surveys, the WEPP Technical document, the WEPP climatological database, and various published articles and theses. Data input requirements and sources are listed in Table 1. The model structure developed for the SID, and a discussion of the development of model parameter values are discussed in Appendix C.

Table 1. WEPP model data input requirements.

Input File	Data Needs	Source
Climate File (Hillslope and Watershed Components)	Meteorology Data, Precipitation, Wind, Temperature, Dew Point	RFETS Records, Supplemented With Nearby Station Data
Slope File	Overland Flow Elements ¹ (OFE), Hillside Length, Width, Slope	RFETS Data AMS Modeling Team, GIS Services
Soil File (One For Each OFE and Channel)	Soil Type, Texture, Porosity, Conductivity, OM, CEC, Albedo, Number and Depth of Soil Layers	RFETS Data, AMS Modeling Team, GIS Services
Plant/Management File (one for each OFE and Channel)	Plant Types, Characteristics, Growth Parameters, Management Practices	RFETS Data, AMS Modeling Team, Ecology
Watershed Structure File	Describes Watershed Configuration	AMS Modeling Team, GIS Services
Watershed Channel File	Characteristics of Channel, Shape, Depth, Erodability, Hydraulic Parameters	Observations by AMS Modeling Team, RMRS Surface-Water Group
Impoundment File	Characteristics of Impoundment and Outlets	Observations by AMS Modeling Team and RMRS Surface Water Group

1. Overland Flow Elements are regions of homogeneous soils, cropping, and management on a hillslope. Each hillslope may have as many as ten OFEs.

6.0 PRELIMINARY RESULTS FOR THE SOUTH INTERCEPTOR DITCH WATERSHED

This report presents preliminary WEPP model results for the hillslope erosion module of WEPP for the SID. Calibration of the watershed module is progressing. Initial attempts progressed slowly due to a programming bug in the WEPP watershed module source code that does not allow for conditions where flow in an upstream channel enters a downstream channel receiving no runoff from the adjacent hillslope. The WEPP technical support personnel at the ARS and Purdue University are working on this problem. This condition occurs in the SID watershed where impervious areas such as paved areas or gravel roads drain to pervious channels (e.g. Hillslopes 3, 4, 9, 10, 15, and 21). For example, the East Access Road (Hillslope 21, Figure C-1) drainage ditch carries flows into the East Spray Field Ditch, which commonly receives no flow from Hillslope 22 during most storm events. This problem has recently been successfully resolved by slightly modifying the input files in a way that did not affect erosion and runoff estimates. The model has produced reasonable estimates of erosion and sediment movement.

WEPP has been run in the hillslope and watershed modes to simulate runoff and erosion for climate data from 1995 and for a 100 year simulation for each hillslope in the SID and for the entire watershed. The model output is contained in ASCII output files that were read into an AccessTM database for summarization and further analysis in spreadsheets. WEPP has the capability to generate a tremendous amount of output for simulated climate characteristics, vegetation parameters, soil parameters, runoff, erosion, and other parameters. The output data presented in this report are for annual average soil erosion and runoff rates and quantities and as total quantities for the entire simulation duration (e.g., 100 years). Output can also be generated by event or by month.

The WEPP output data for average annual rates were used for this report. The results obtained include:

- The number of storms occurring over the simulations;
- The number of rain and snow runoff events over the simulations;
- The amount of precipitation occurring over the simulations;
- The annual average precipitation over the simulations;
- The amount of precipitation occurring as rain and as snow;
- The amount of runoff generated on an annual average and over the simulations that is due to rain and snowmelt;
- The amount of soil erosion or deposition at evenly spaced distances along the length of each OFE;

- The total amount of sediment delivered to the receiving channels on an annual average and over the duration of the simulations;
- The average erosion rate for the hillslope in units of metric tons (1000 kg or about 2200 pounds) per hectare (10,000 m² or 2.47 acres);
- The average erosion rate for the hillslope in units of kilograms per meter (kg/m) of hillslope width; and
- The aggregate size distribution of sediment leaving the hillslope.

Estimates of runoff and erosion for each hillslope are contained in Table 2 for the 1995 simulation and in Table 3 for the 100-year simulation. Estimates of channel flow and sediment transport for the 1995 and 100-year simulations for the entire SID watershed are given in Tables 4 and 5.

Output by precipitation event will also allow an analysis of the types of storms or sequences of storm that produce the most significant amounts of erosion. Storm return periods and probabilities of occurrence will be calculated for significant events.

Developing ways of mapping the WEPP model results to estimate a spatial representation of erosion and sediment movement on hillslopes is an ongoing activity for the study. The WEPP output consists of the amount of erosion or deposition (in kg/m) occurring at 100 equally-spaced intervals along the length of each hillslope element (OFE). The information in the WEPP slope input file must be recombined with the WEPP output in order to display the output spatially using geographic information systems (GIS) techniques.

In GIS, the original transects used to measure the slopes of each OFE (i.e. for the slope input file) were used to display the WEPP erosion values. The estimated erosion values are evenly distributed along the transects for each OFE. A preliminary map demonstrating the output of the methodology under development is shown in Figure 2. In the final version estimated erosion rates will be shown on the maps. A final erosion map will be generated for the entire SID watershed and for the Woman Creek and Walnut Creek watersheds. The erosion map coverage will be combined with the spatial distribution of the actinides from the Kriging analysis (Appendix A) to produce an actinide mobility map.

6.1 Discussion of Results and Comparison to Measured Data

Inspection of Tables 2 through 6 and Figure 2 along with Appendix Figure C-1 and C-4 indicates that the WEPP model is producing realistic erosion estimates. Erosion is predicted on disturbed and/or steeply sloped areas, and deposition on flatter and /or well-vegetated areas.

Table 2. Preliminary WEPP Modeling Results for 1995 Simulation of Erosion in the South Interceptor Ditch Watershed

HILLSLOPE	NUMBER OF RAIN RUNOFF EVENTS	NUMBER OF SNOW RUNOFF EVENTS	TOTAL RAIN RUNOFF (mm / 5 Yrs)	TOTAL SNOW RUNOFF (mm / 5 Yrs)	MEAN ANNUAL RUNOFF DEPTH (mm / Yr)	MEAN ANNUAL RUNOFF YIELD (m ³ / Yr)	ANNUAL HILLSLOPE SOIL LOSS (Kg)	ANNUAL HILLSLOPE SOIL YIELD / AREA (Kg / Ha)
SID HILLSLOPE 1	30	5	52	0	10.4	553	11.1	2
SID HILLSLOPE 3	96	20	214	137	70.2	3036	1080	250
SID HILLSLOPE 4	81	12	79	41	23.9	495	0.001	0
SID HILLSLOPE 6	60	7	340	121	92.1	48	171	3274
SID HILLSLOPE 7/9	145	120	39	0	7.8	323	0.001	0
SID HILLSLOPE 10	100	23	92	0	18.4	987	280	52
SID HILLSLOPE 11	25	5	13	86	19.7	11	213	3735
SID HILLSLOPE 12	44	7	69	1	14	119	4.71	6
SID HILLSLOPE 13	17	7	3	2	0.9	33	4.74	1
SID HILLSLOPE 14	47	5	52	0	10.3	221	2.91	1
SID HILLSLOPE 15	87	22	4	8	2.4	126	30.3	6
SID HILLSLOPE 16	35	5	49	0	9.8	405	0.411	0
SID HILLSLOPE 17	65	10	178	14	38.2	73	974	5130
SID HILLSLOPE 18/19	96	24	39	0	7.7	773	8.32	1
SID HILLSLOPE 19/20	41	10	46	0	9.2	743	0.019	0
SID HILLSLOPE 21	85	15	532	450	196	1176	0.001	0
SID HILLSLOPE 23	19	0	28	0	5.6	130	3.08	1
SID HILLSLOPE 25	19	0	78	0	15.5	99	0.001	0
SID HILLSLOPE 26	19	0	78	0	15.5	146	0.002	0
SID HILLSLOPE 27	19	0	77	0	15.4	8	0.000	0

Note: Rocky Flats meteorological data for 1995 has 551 mm precipitation.

Table 3. Preliminary WEPP Modeling Results for a 100-Year Simulation of Erosion in the South Interceptor Ditch Watershed

HILLSLOPE	NUMBER OF RAIN RUNOFF EVENTS	NUMBER OF SNOW RUNOFF EVENTS	TOTAL RAIN RUNOFF (mm / 100 Yrs)	TOTAL SNOW RUNOFF (mm / 100 Yrs)	MEAN ANNUAL RUNOFF DEPTH (mm)	MEAN ANNUAL RUNOFF YIELD (m ³)	ANNUAL HILLSLOPE SOIL LOSS (Kg)	ANNUAL HILLSLOPE SOIL YIELD / AREA (Kg / Ha)
SID HILLSLOPE 1	990	77	1270	80	13.5	718	851	160
SID HILLSLOPE 3	1073	82	5388	512	58.9	2547	17766	4108
SID HILLSLOPE 4	1158	85	4167	383	45.4	940	20.3	10
SID HILLSLOPE 6	744	51	4921	457	53.7	28	82.5	1581
SID HILLSLOPE 7/9	2328	956	1038	117	11.4	472	0.438	0
SID HILLSLOPE 10	1268	126	1245	170	14.1	756	682	127
SID HILLSLOPE 11	735	49	4240	367	46	26	168	2955
SID HILLSLOPE 12	1109	112	963	127	10.8	92	106	125
SID HILLSLOPE 13	643	40	873	41	9.1	331	370	102
SID HILLSLOPE 14	1148	105	1486	152	16.3	350	80.9	38
SID HILLSLOPE 15	944	64	912	59	9.6	502	594	114
SID HILLSLOPE 16	1004	80	1188	138	13.1	541	15.2	4
SID HILLSLOPE 17	1256	133	1581	217	17.9	34	1187	6250
SID HILLSLOPE 18/19	1319	109	721	70	7.9	793	3285	327
SID HILLSLOPE 19/20	524	30	639	66	6.9	558	5510	682
SID HILLSLOPE 21	1088	68	8999	861	98.5	590	0.006	0
SID HILLSLOPE 23	162	12	949	59	9.9	231	413	177
SID HILLSLOPE 25	187	23	1609	226	18.2	117	79.5	124
SID HILLSLOPE 26	187	23	1494	224	17.1	161	260	275
SID HILLSLOPE 27	186	23	1754	227	19.7	10	3.38	66

Note: Simulation includes 7986 precipitation events, generating an average annual precipitation of 369 mm.

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Table 4 Preliminary WEPP Modeling Results for the 1995 Simulation of Erosion in the South Interceptor Ditch Watershed.

HILLSLOPE ¹	CHANNEL	MEAN ANNUAL HILLSLOPE RUNOFF (mm/yr)	MEAN ANNUAL SEDIMENT YIELD (kg/yr)	MEAN ANNUAL CHANNEL DISCHARGE VOLUME (m ³ /yr)	MEAN ANNUAL CHANNEL DISCHARGE VOLUME (AF/yr)
1		554	11		
3		2923	1055		
	50		1100	3504	2.84
6		48	171		
	53		1300	3552	2.88
4		463	0		
	55		200	347	0.28
7_9		326	0		
	56_57		1600	4214	3.42
10		986	280		
	63		1900	5215	4.23
11		11	213		
	61_62		0	2.5	0.002
12		119	5		
	64		1900	5336	4.33
14		221	3		
	66		1.800	5537	4.49
13		36	5		
	65		500	56	0.05
16		407	0.4		
	68		2700	6130	4.97
15		124	28		
	67		500	137	0.11
17		72	974		
	69		3700	6209	5.03
18_19		726	8.3		
	70_71		2400	5979	4.85
19_20		746	0		
	71_72		3800	6771	5.49
21		1176	0		
	73_74		100	957	0.78
23		131	3.1		
	75		400	891	0.72
25		100	0		
26		146	0		
	77		100	1091	0.88
27		8	0		
	79		4700	7886	6.39

1. Includes 108 precipitation events, generating an average annual precipitation of 551 mm (21.7 inches). The routing diagram (Appendix Figure C-2) shows the flow routing for the SID. The SID watershed consists of a major drainage channel and tributary channels 55, 61_62, 65, 67, and 77 (Appendix Figure C-1).

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Table 5 Preliminary WEPP Modeling Results for the 100 Year Simulation of Erosion in the South Interceptor Ditch Watershed.

HILLSLOPE ¹	CHANNEL	MEAN ANNUAL HILLSLOPE RUNOFF (mm/yr)	MEAN ANNUAL SEDIMENT YIELD (kg/yr)	MEAN ANNUAL CHANNEL DISCHARGE VOLUME (m ³ /yr)	MEAN ANNUAL CHANNEL DISCHARGE VOLUME (AF/yr)
1		696	826		
3		2495	17745		
	50		15100	2959	2.40
6		28	82		
	53		15200	2987	2.42
4		910	20		
	55		300	862	0.70
7_9		468	0.2		
	56_57		15800	4131	3.35
10		726	681		
	63		16400	4782	3.88
11		26	169		
	61_62		200	24	0.02
12		90	105		
	64		16500	4876	3.95
14		346	70		
	66		14800	4994	4.05
13		323	363		
	65		2200	321	0.26
16		537	11		
	68		18300	6075	4.93
15		496	580		
	67		1800	497	0.40
17		33	1111		
	69		19500	6113	4.96
18_19		772	3276		
	70_71		8900	4977	4.04
19_20		562	5468		
	71_72		21000	5346	4.34
21		589	0		
	73_74		100	255	0.21
23		236	412		
	75		500	411	0.33
25		116	80		
26		160	260		
	77		1100	668	0.54
27		10	3		
	79		15100	5989	4.86

1. Includes 7986 precipitation events, generating an average annual precipitation of 369 mm (14.5 inches). The routing diagram (Appendix Figure C-2) shows the flow routing for the SID. The SID watershed consists of a major drainage channel and tributary channels 55, 61_62, 65, 67, and 77 (Appendix Figure C-1).

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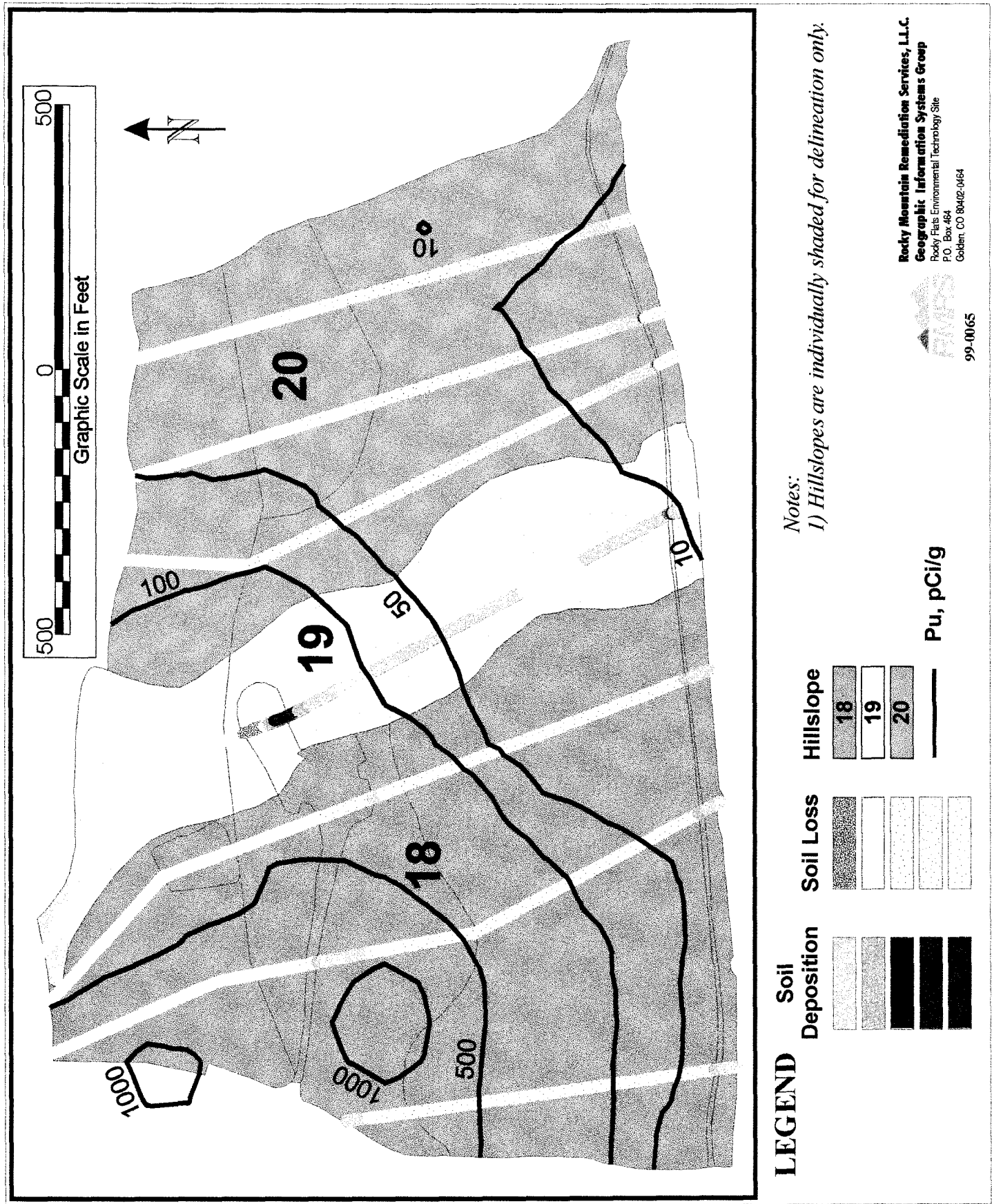
Table 6. Comparison of Preliminary WEPP Model Output for the South Interceptor Ditch to the Loading Analysis Calculations¹.

Parameter	WEPP 1995 Estimate	Loading Analysis 1995 Value	WEPP 100-Year Estimate	Loading Analysis 3-Year Average
Annual Average Soil Erosion (kg/ha)	74	78	237	42
Annual Total Soil Transport to SID Outlet (kg)	4,700	4,961	15,100	2,654
Annual Average Runoff (m ³)	7,886	77,718	5,989	41,326
SID Watershed Runoff Coefficient (RC)	0.02	0.23 (RC = 0.08 in Water Year 1996)	0.03	0.14

[Note: Runoff Coefficient is the fraction of precipitation that runs out watershed outlet.]

¹ The WEPP output and Loading Analysis values are computed as the total sediment/runoff leaving the SID outlet.

Figure 2. Preliminary GIS Representation of WEPP Model Output for Erosion on Hillslopes 18, 19, 20.



Evaluation of the results in Table 2 and 3 indicates that disturbed areas such as unimproved roads (e.g. Hillslopes 6, 11, and 17) and the area around Building 460 (Hillslope 3) have the largest erosion rates (t/ha). However, these areas do not contribute an inordinate amount of total sediment yield to the SID. The model also estimates that about 40 percent of the sediment exiting the SID is resuspended from the SID channel. This appears to be supported by observations that small events tend to deposit sediments in the channel and large events produce enough flow to scour the channel.

Tables 4 and 5 show the estimated average annual amounts of runoff and sediment leaving the hillslopes and the amounts of flow and sediment discharged at the downstream end of each channel element. Comparing these results to Table 6, reveals that the estimate of sediment delivery at the outlet (4,700 kilograms (kg) of soil for 1995 or 74 kg of soil per hectare per year) compares very well with the 1995 monitoring data for the SID outlet, but that runoff was underestimated by a factor of 10. A review of the sensitive parameters is currently underway by the modeling group to determine if parameter changes may be made that will lead to a more accurate estimation of runoff. The WEPP model developers are also being consulted.

The WEPP model, as configured for the SID, under-predicted runoff but predicted sediment movement very well. According to Zhang et al. (1996), this is typical of WEPP model simulations. These discrepancies will be minimized as the model continues to be calibrated to Site conditions. The WEPP model results are consistent with field observations by Site surface water monitoring personnel, and indicate that only large storm events or normal events occurring with high antecedent moisture conditions produce runoff on the vegetated, undisturbed areas of the Site. Zika (1996) also discussed the same runoff characteristics for Site rainfall simulation experiments conducted near the 903 Pad in the SID watershed.

6.2 Model Calibration Tasks

Calibration of the many components of the SID WEPP model will be completed in FY 1999. For example, Hillslope 15 (Figure C-1) appears to be contributing the most sediment to the SID, but the contribution from Hillslope 15 is disproportionately large compared to other SID hillslopes with similar soil, vegetation, and hydrologic characteristics. The hillslope is configured such that flow comes off of an impervious surface, then across a large, unimproved road surface prior to flowing over grassland. The hillslope structure or parameterization may be causing the apparently high predicted erosion rate on Hillslope 15. Currently, the WEPP model for the SID does not contain any impoundment structures such as silt fences, ponds, straw bales, and other sediment traps which are present in some areas. Programming these types of impoundments into the WEPP model at the bottom of the hillslopes will decrease the predicted sediment yields for each hillslope.

Other calibration procedures for FY 1999 include:

- Improving runoff predictions for impervious areas, e.g. hillslopes 3, 4, 9, 10, and 21);

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- Adjustment of the model soil parameters and vegetation parameters to generate increased sediment delivery for hillslopes 3 and 4, which have been measured to contribute significant quantities of sediment from road sanding in winter and spring; and
- Adjustment of the model soil parameters to more closely reflect actual amounts of runoff as measured at channel gaging stations.

7.0 FISCAL YEAR 1999 WEPP MODELING ACTIVITIES

Many activities are planned for FY 1999 to investigate actinide transport by overland flow and erosion processes. The following field data collection and computer modeling activities are planned.

- During FY 1999 the watershed erosion modeling effort will be applied to both Woman and Walnut Creek Watersheds and calibrated to the Loading Analysis.
- If necessary, a suitable flow and sediment transport routing model will be selected, calibrated, and used to estimate sediment and associated actinide transport. The routing model will estimate the quantities of water, sediment, and associated actinides that are transported off-Site by integrating the runoff and sediment delivery estimates for each hillslope into a watershed configuration as illustrated by the SID routing diagram (Appendix Figure C-2).
- The WEPP model will be calibrated further to match observed Site conditions. For example, sensitive WEPP parameters such as soil hydraulic conductivity, vegetative cover, rock cover, and other parameters will be adjusted to produce simulated runoff and erosion estimates that approximate field measurements.
- WEPP will be used to simulate runoff and erosion for individual storms, such as the May 17, 1995 flood.
- Erosion and actinide mobility will be mapped using GIS technology. The watershed modeling group is developing the methodology for spatial display of WEPP output. GIS will be used to combine the WEPP output with the spatial distribution of soil activity to produce an actinide mobility map.
- Field measurements of runoff and erosion at gaging stations GS41 and GS42 will continue for WEPP calibration.
- The CSM study on soil aggregation characteristics and actinide particle-size associations is anticipated to be completed in calendar year 1998. Results from this study will complement the WEPP model results to make conclusions about the fate of actinides mobilized by erosion and sediment transport processes.
- A study funded by the DOE Headquarters via an Environmental Management Science Program (EMSP) Grant might be conducted at Rocky Flats in the early summer of 1999 if additional funding for Site support is provided by DOE. Colorado State University (CSU), in conjunction with Los Alamos National Laboratory (LANL), is interested in conducting an investigation of soil erodibility by artificial rain water application onto small soil plots at several Site locations. The results of the study would not be available in time to benefit the WEPP modeling study.

However, relevant, preliminary data, if available, from the study will be used to calibrate WEPP to Site conditions.

Estimation of erosion and associated actinide transport in the SID, Woman Creek, and Walnut Creek drainage basins, using the WEPP model, will be completed in FY 1999. A final report that describes the model calibration and presents the results of the modeling study will be prepared. The report may include, but is not limited to, the following elements:

- Erosion maps;
- Actinide mobility maps;
- Estimation of off-Site actinide discharges;
- Calibration data for WEPP ;
- Comparison of modeled results to field measurements; and
- Sensitivity analysis for WEPP.

FY 2000 work products will be planned in FY 1999. The current plan for FY 2000 includes estimating erosion, actinide transport and off-Site impacts under different potential Site configurations and hydrologic conditions. For example, runoff and erosion are expected to be different when engineered, revegetated caps cover the currently industrialized area. Elimination of the detention structures in the Woman Creek and Walnut Creek watersheds, catastrophic weather and "acts of God" such as grass fires and flooding and remediation of actinide source terms will be modeled in FY 2000.

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APPENDICES

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APPENDIX A

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A.1 SPATIAL ANALYSIS OF PU-239/240 DISTRIBUTIONS IN SURFACE SOILS

A total of 1,314 Pu-239/240 samples were analyzed across the RFETS. With the exception of the 1998 sampling (65 samples, see Section 4), all samples used in this analysis were taken between June, 1991 and February, 1995. Values of Pu-239/240 range from non-detect to 14,950 pCi/g, and are greater near the 903 Pad. Analysis of data values indicates that the distribution of data is highly skewed, with 99 percent of the samples registering levels less than 1 percent of the maximum (14,950 pCi/g), and agrees favorably with previous work at RFETS (Little and Whicker, 1978).

Spatial distribution of the samples also shows high variability, ranging in separation of 25 feet between samples to over 4,000 feet. Clustering of data points is evident in a number of areas, particularly near the 903 Pad. Spacing generally increases as sampling distance from that location increased. Spatial analysis of the data values shows significant ranges of values over short distances. In one example, a sample showing Pu-239/240 levels of 5,700 pCi/g was less than 500 feet from another sample having a Pu-239/240 value of less than 5 pCi/g. Another example shows a sample registering nearly 1200 pCi/g only 15 feet from another only registering 348 pCi/g. This high degree of variability supports suggestions of data "hot spots" across the Site mentioned in previous studies (Litaor, 1995).

A.2 GEOSTATISTICAL APPROACH

Kriging was selected as the technique to best analyze the data across the entire RFETS, because of its statistical approach. Kriging is based on the regionalized variable theory that assumes that the spatial variation in the phenomenon represented by the z-values is statistically homogeneous throughout the surface (i.e., the same pattern of variation can be observed at all locations on the surface). This hypothesis of spatial homogeneity is fundamental to the regionalized variable theory (Meyers, 1997).

The spatial variation is quantified by the semi-variogram. The semi-variogram is estimated by the sample semi-variogram, which is computed from the input point data set. The value of the sample semi-variogram for a separation distance of h (referred to as the lag) is the average squared difference in z-value (measure of spatial variation) between pairs of input sample points separated by h . The semi-variogram is modeled by fitting a theoretical function to the sample semi-variogram (Meyers, 1997).

One type of Kriging, Ordinary Kriging, requires that some assumptions be made by the user to best represent the relationship of the data in the study area. In particular, appropriate mathematical functions must be defined. Kriging uses the mathematical functions specified to fit a line or curve to the semi-variance data in the semi-variogram. Standard functions used include spherical, circular,

exponential, Gaussian and linear. Ordinary Kriging assumes that the variation in z-values is free of any structural component (drift). Drift is a systematic change in the z-values in a particular direction. Universal Kriging assumes some type of constant structural drift, and that the local trend varies from one location to another. Universal Kriging is best fitted to data where drift is known to occur, such as a hillside (Meyers, 1997). Ordinary Kriging was used for purposes of this study because there is no constant drift observed in any particular direction.

A.3 METHODOLOGY

The extreme variability of the data poses significant challenges to a statistical approach, such as Kriging. The wide range and skewing of data values, coupled with rapid changes in recorded levels over relatively small distances, sometimes amounting to several orders of magnitude, is of particular significance. A generalized approach, such as Kriging, often has difficulty with such extreme variations. In an effort to resolve these issues, a similar approach was adopted as was used in previous studies to model the distribution of data (Little and Whicker, 1978; and Litaor, 1995). All work was performed in Arc/Info 7.1.2 (ESRI, 1998), including Kriging of the data and contour generation.

The data was first analyzed to determine a suitable step size. Examination of the sample spacing indicated that the distance between samples varied between 25 and 4,000 feet, with the majority of samples located within 300 feet of each other. Semi-variograms were then generated at various step sizes between 25 and 300 feet. Comparison of those semi-variograms, along with generation of grid at those step sizes, indicated that semi-variograms generated with a step size of 75 feet most closely approximates the distribution of the data. Re-examination of the data shows that samples separated by 25 feet are clustered in a relatively few areas, with the majority of the remainder of the data showing a separation of 75 feet or greater.

The second step in the process was to model data distribution. As mentioned earlier, that analysis of the data revealed a significant skewing of the data, resulting in non-normal distribution. Following previous analysis performed on the RFETS data (Litaor, 1995), that data was transformed using a natural log (Y_i) function. This procedure had the effect of improving the stability of the data by providing a more normal data distribution, thereby reducing the skew (Little and Whicker, 1978).

Using lognormal data, analysis was performed to determine which Kriging function most accurately reflected the spatial distribution of data. Semi-variograms were generated using linear, spherical, circular, exponential, and Gaussian functions to model the data distribution. Comparisons of each function indicate that the Gaussian function best represents the data. The chosen Gaussian function has the form:

$$\gamma(h) = C_o + C \left[1 - \exp\left(-\frac{3h^2}{R^2}\right) \right]$$

Where:

- h = Distance (feet)
- C_o = Residual Correlation (Nugget Effect)
- C = Correlation Coefficient
- R = Range (distance (feet) at which 95% of the maximum is achieved)
- Sill = Maximum Value Achieved

The parameters generated in conjunction with the results of the semi-variogram were used then to generate a Kriged surface the best represents the data (see Tables and Figures A-1 and A-2). The Kriged surface was transformed back to the original scale, and contours were generated from that surface at user-specified intervals.

A.4 PU-239/240 RESULTS

Calculation of the optimal Gaussian function for Pu-239/240 resulted in a function as defined by a semi-variogram (Figure A-1). This semi-variogram, although a better overall representation of the data distribution as a result of the lognormal data conversion, never the less had difficulty with the "hot spots" as discussed earlier. In particular, the extreme variation of data in and around the 903 Pad resulted in contours values the matched some, but not all of the data points. In some cases significant differences between the predicted and actual can be found because of the difficulty that the Kriging algorithm had in dealing with these localized "hot spots."

The final results are shown in Table 1, where the optimal calculated parameters for the Gaussian function are shown. Note that, because all Kriging analysis is performed on lognormal data, that all Kriging parameters shown are lognormal in scale. Figure 1 shows resulting semi-variogram, and depicts the lognormal of the samples compared in increasing step sizes, beginning with 75 feet and increasing to 6,000 feet.

Figure A-1. Pu-239/240 Semi-Variogram.

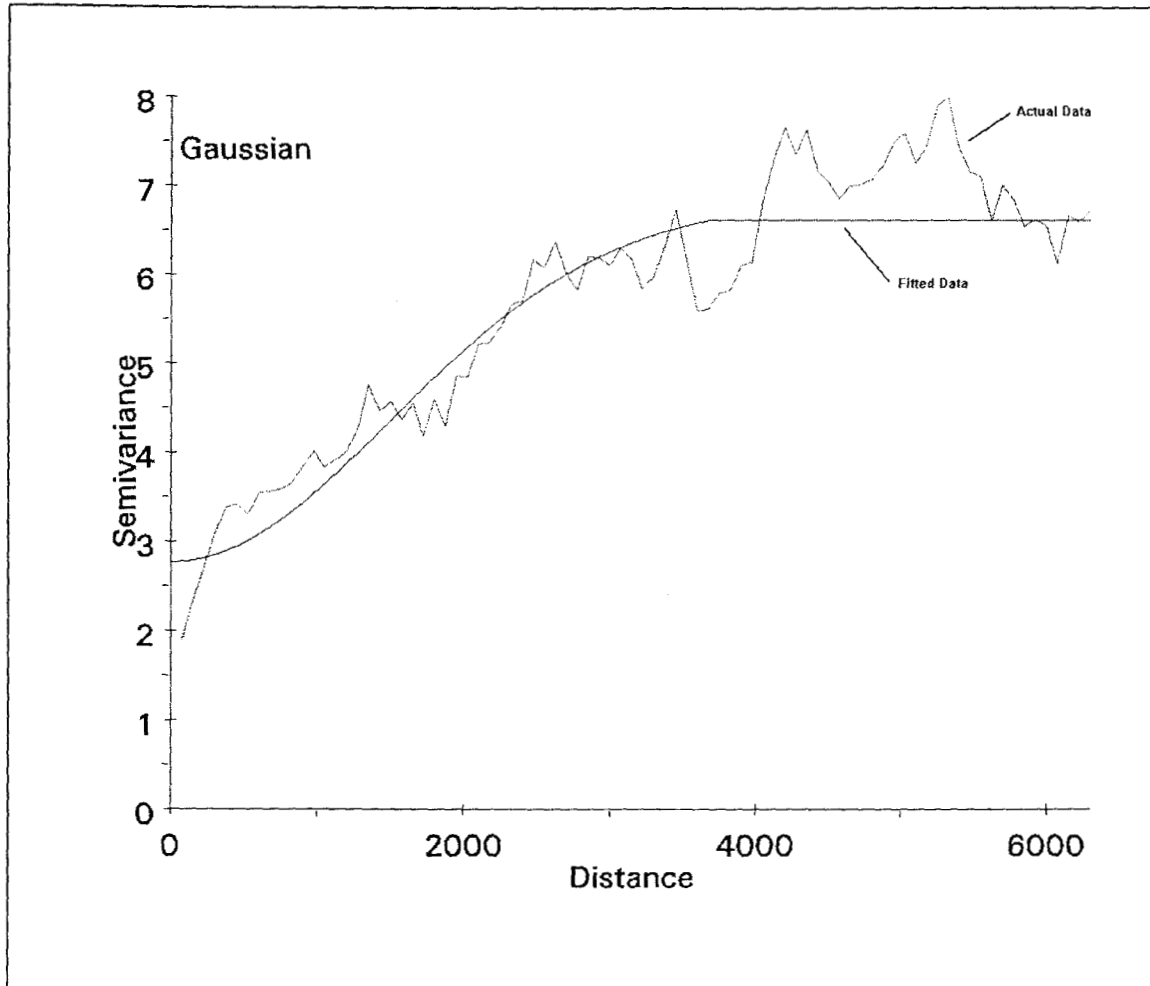


Table A-1. Gaussian Kriging Parameters for Pu-239/240.

Pu-239/240 Kriging Parameters		
Parameter	Value(ln)	Value
c0	2.7	14.880
C	4.044	57.054
R	2121.709	n/a
Sill	6.611	743.226

A.5 AM-241 RESULTS

Results from the analysis of Am-241 data are shown in the semi-variogram shown in Figure A-2. Like Figure A-1, lines for both the actual and fitted data are shown for step sizes from 75 feet to 12,000 feet, which is the maximum offset distance. Although the fitted semi-variogram does not appear to follow the data as closely as the one shown for Pu-239/240, the contours resulting from the Kriged surface tend to show a slightly better agreement, particularly in the 903 Pad Area. This is due, in part, to the smaller range between the maximum and minimum detections of Am-241, along with a more normal distribution of data. Calculations for the equivalent data for Am-241 resulted in the Gaussian function parameters shown in Table A-2.

A.6 RESULTS

Kriged contours generated from the Pu-239/240 and Am-241 data indicate a strong west-to-east trend (Figures A-3, and A-4). Highest values are found near the 903 Pad, and rapidly decrease with distance from that area. Current Kriging results show strong agreement with previous work (Litaor, 1995). Previous Kriging results did not have the benefit of data in the northeastern quadrant of the Site (Walnut Creek watershed). Primary differences can be attributed to the number of samples utilized. Where previous Kriging studies evaluated only the 118 Pu-239/240 and Am-241 samples (Litaor, 1995) captured using Colorado Department of Health binding protocols (Bernhardt et.al, 1983) to draw their conclusions, this study evaluated all samples currently available. This increased sample base allowed reduced step size, resulting in contours of improved detail. It was for these reasons that the AMS decided that it was important to update historical representations of the actinide distributions for integration with the erosion estimates provided by the WEPP watershed erosion model to ultimately generate an actinide mobility map for surface soils, based on particulate transport by overland flow (erosion).

Figure A-2. Am-241 Semi-Variogram.

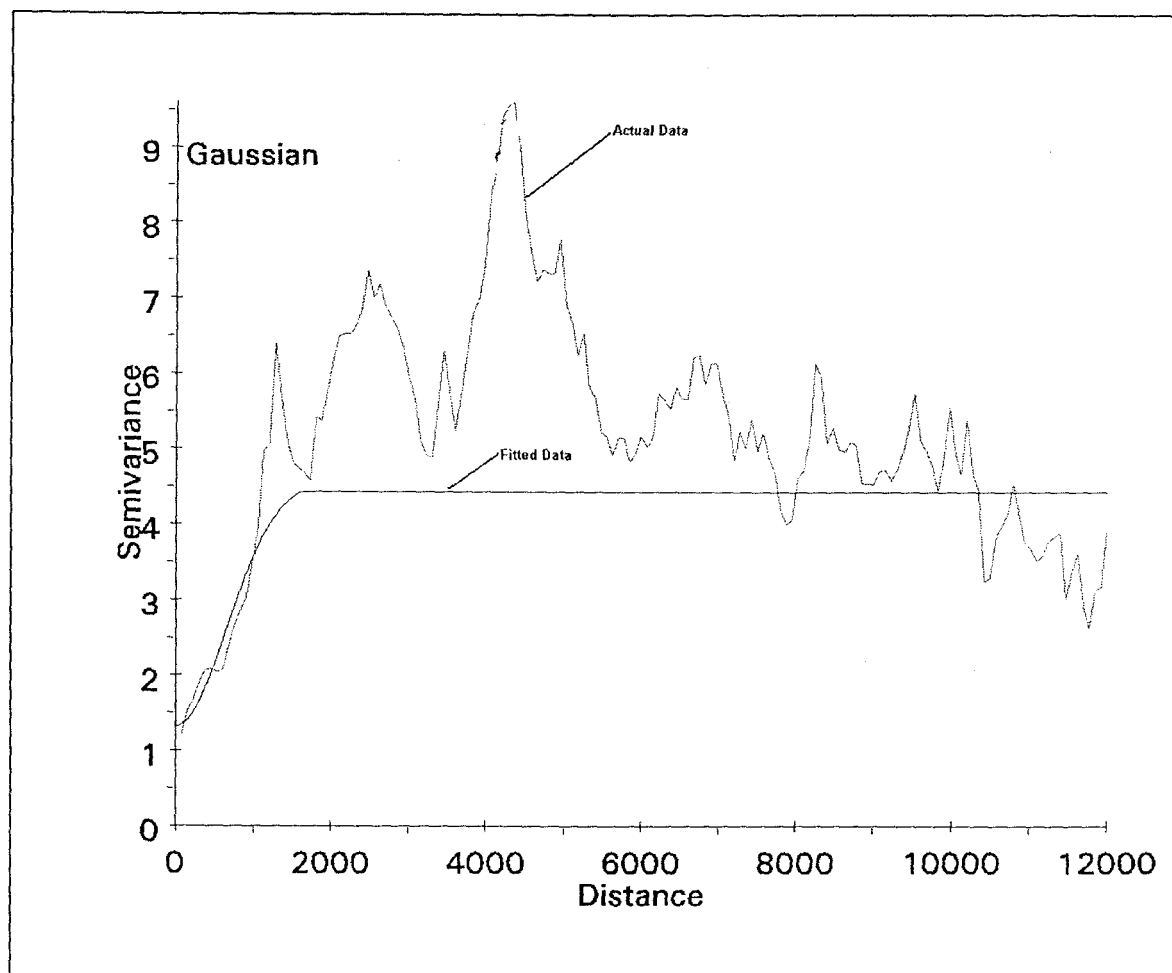


Table A-2. Gaussian Kriging Parameters for Am-241.

Am-241 Kriging Parameters		
Parameter	Value (ln)	Value
C_0	1.318	3.736
C	3.273	26.39
R	920.918	n/a
Sill	4.428	83.764








Figure A-3. Am-241 Isoplot (pCi/g) (1998 Kriging Analysis).

Appendix A-3

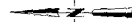
Pu-239/240 Isopleth (pCi/g)
(1998 Kriging Analysis)

EXPLANATION

Standard Map Features

-  Buildings and other structures
-  Solar evaporation ponds
-  Lakes and ponds
-  Streams, ditches, or other drainage features
-  Fences and other barriers
-  Rocky Flats boundary
-  Paved roads

DATA SOURCE:
Buildings, fences, hydrography, roads and other features are shown as they appear in 1998. Data were prepared by ES&S T&E, Inc. from digitized data from the orthophotographs, 1998.



Scale = 1 : 32250
1 inch represents approximately 2688 feet

0 1000 2000
feet

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

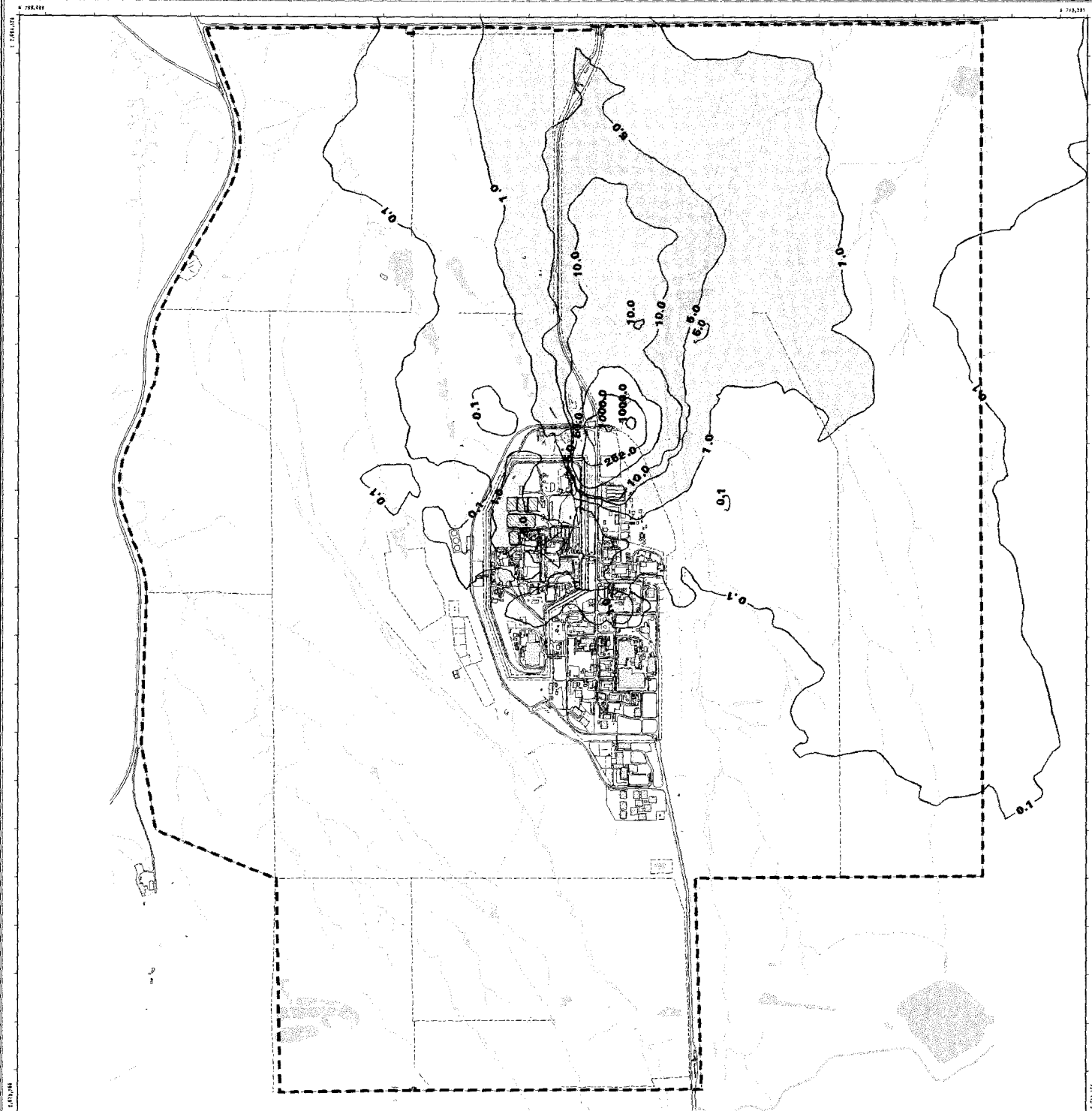
Prepared by:



Rocky Mountain
Remediation Services, L.L.C.
Geographic Information Systems Group
P.O. Box 7502, Lakewood, Colorado 80424-7502
Phone: 303 943-4444

MAP ID: 98-0274

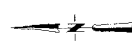
November 30, 1998



Appendix A4 Am241 Isopleth (pCi/g) (1998 Kriging Analysis)

- EXPLANATION**
- Standard Map Features**
- Buildings and other structures
 - Solar evaporation ponds
 - Lakes and ponds
 - Streams, ditches, or other drainage features
 - Fences and other barriers
 - Rocky Flats boundary
 - Paved roads

DATA SOURCES:
Buildings, fences, hydrography, roads and other features were digitized from aerial photographs acquired by EG&G FSI, Inc. in 1998. Digitized from the orthophotographs. 1/95



Scale = 1 : 32250
1 inch represents approximately 2688 feet



State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site



**Rocky Mountain
Remediation Services, LLC**
Geographic Information Systems Group
Rocky Flats Environmental Technology Site
Golden, CO 80402-2444

MAP ID: 98-0274

November 23, 1998



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APPENDIX B

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B.1 SOUTH INTERCEPTOR DITCH LOADING ANALYSIS RESULTS

There is only one gaging station (SW027) on the SID (Figure B-1). All of the other gaging stations, in the SID watershed, are located on tributaries to the SID. Table B-1 shows that about 90 percent of the solids entering the SID between the Building 460 culvert (GS22) and the Building 881 Hillside (GS21, GS24, and GS25) are removed by deposition in the SID channel.

Some smaller tributary inflows occur east of the 881 Hillside that are not measured for this study. These tributaries are:

- Two channels that route inner IA perimeter road runoff to the SID;
- A road that once supported traffic from the East Access Road to Pond C-1 which was revegetated in 1996; and
- A channel that carries runoff from the East Access Road and former East Spray Fields to the eastern end of the SID.

These tributaries are being evaluated. The Mass Loading Analysis (RMRS, 1998b) data indicate that the SID is filling with sediment and thus limiting transport of TSS and associated radionuclides. The WEPP model will be calibrated to predict similar sediment deposition in the SID channel.

The data show (Table B-5) that approximately 447 micrograms (μg) of Pu-239/240, 78 μg of Am-241, and 250 kg of U are annually discharged to Pond C-2. It appears that nearly all of this material is settling out of the water column in Pond C-2 due to the fact that the quantity of Pu-239/240 measured in Woman Creek at GS01 is an order of magnitude lower than the quantity discharged to Pond C-2. Approximately 2,650 kilograms of sediment are annually discharged to Pond C-2. The estimated soil erosion rate in the SID drainage is about 0.0002 cm per year, and the runoff coefficient is estimated to be about 0.14 for the entire sub-basin.

Therefore, actinide transport due to soil erosion in the SID watershed appears to be small. Preliminary results from the watershed modeling (see Section 7) appear to confirm this finding.

Table B-1. Summary of Estimated Actinide and TSS Annual Total Yields, Based on Data from 1991 through 1997 (RMRS 1998b).

SOUTH INTERCEPTOR DITCH GAGING STATIONS	ANALYTE	ESTIMATED ANNUAL YIELD (Pu & Am in mg U in g & TSS in kg)	ESTIMATED ANNUAL YIELD / ACRE (Pu & Am in mg / acre, U in g/acre & TSS in kg / acre)	ESTIMATED ANNUAL SOIL EROSION DEPTH IN DRAINAGE BASIN (cm)
GS21 IA Runoff from Cactus and 7th Near Bldg. 664 Drainage Area: 2.66 Acres	Pu Am U TSS	1 1 2 271	0.47 0.31 1 102	0.002
GS22 Bldg. 460 Runoff and Footing Drain Discharge to SID Drainage Area: 14.1 Acres	Pu Am U TSS	4 12 34 5,657	0.25 1 2 401	0.01
GS24 Bldg. 881 and 850 Runoff to 881 Hillside Drainage Area: 5.84 Acres	Pu Am U TSS	1 0 1 333	0.22 0.07 0.22 57	0.001
GS25 East Bldg. 881 and 891 Hillside Runoff with 881 Sump Flows Drainage Area: 6.7 Acres	Pu Am U TSS	1 1 7 401	0.18 0.10 1 60	0.001
SW027 South Interceptor Ditch (SID) at Inflow to Pond C-2 Drainage Area: 186 Acres	Pu Am U TSS	447 78 250 2,654	2 0.42 1 14	0.0002

Table B-2. Runoff Coefficients for the SID Gaging Stations.

WATER YEAR	GAGING STATION	AREA (Acres)	MEASURED ANNUAL PRECIPITATION (Feet)	ESTIMATED POTENTIAL ANNUAL YIELD (Acre-Feet)	MEASURED ANNUAL YIELD (Acre-Feet)	COMPOSITE BASIN ESTIMATED RUNOFF COEFFICIENT (Unitless)
1995	SW027	186	1.48	275	63	0.23
1996	SW027		1.02	190	15.5	0.08
1997	SW027		1.20	222	22	0.10
					AVERAGE:	0.14
1995	GS21	2.66	1.48	3.9	2.5	0.64
1996	GS21		1.02	2.7	1.1	0.40
					AVERAGE:	0.52
1995	GS22	14.1	1.48	20.8	19.7	0.95
1996	GS22		1.02	14.4	10.9	0.76
					AVERAGE:	0.85
1995	GS24	5.84	1.48	8.6	1.6	0.19
1996	GS24		1.02	6.0	0.63	0.11
					AVERAGE:	0.15
1995	GS25	6.7	1.48	9.9	7	0.71
1996	GS25		1.02	6.9	2.2	0.32
					AVERAGE:	0.51

Notes:

- 1) Values in italics for water year 1995 are estimated based on 6 months of continuous record.
- 2) Values for GS22 measured yield do not include base-flow of approximately 0.025 cubic feet/second.

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APPENDIX C

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C.1 Model Structure for the South Interceptor Ditch

C.1.1 Hillslope and Channel Configurations

The SID watershed was divided into discrete hillslopes draining to channel segments and impoundments using logical hydrologic divides that are either natural or man-made. Hillslope and channel delineation were made in the field on five-foot contour interval mapping provided by the RMRS GIS personnel. RMRS personnel were accompanied by Colorado Department of Public Health and the Environment (CDPHE) personnel to walk the entire SID watershed and delineate the hillslopes and channels. The SID watershed boundaries were modified from the boundaries in the Rocky Flats Plant Drainage and Flood Control Master Plan (EG&G, 1992). A map of the SID watershed hillslopes and channels is shown in Appendix Figure C-1.

The hillslopes and channels were delineated to provide reasonable resolution for estimation of runoff and erosion without making the model unnecessarily complex. Some of the hillslope and channel lengths exceed the recommended lengths for WEPP. Therefore, the authors of WEPP at the ARS Southwest Erosion Research Station in Tucson, Arizona were consulted to review the hillslope and channel delineations, and their assessment concluded that the hillslopes and channels were reasonable. Mokhothu (1996) showed that increasing the complexity of the WEPP watershed model did not improve the accuracy of the model predictions for a small rangeland watershed.

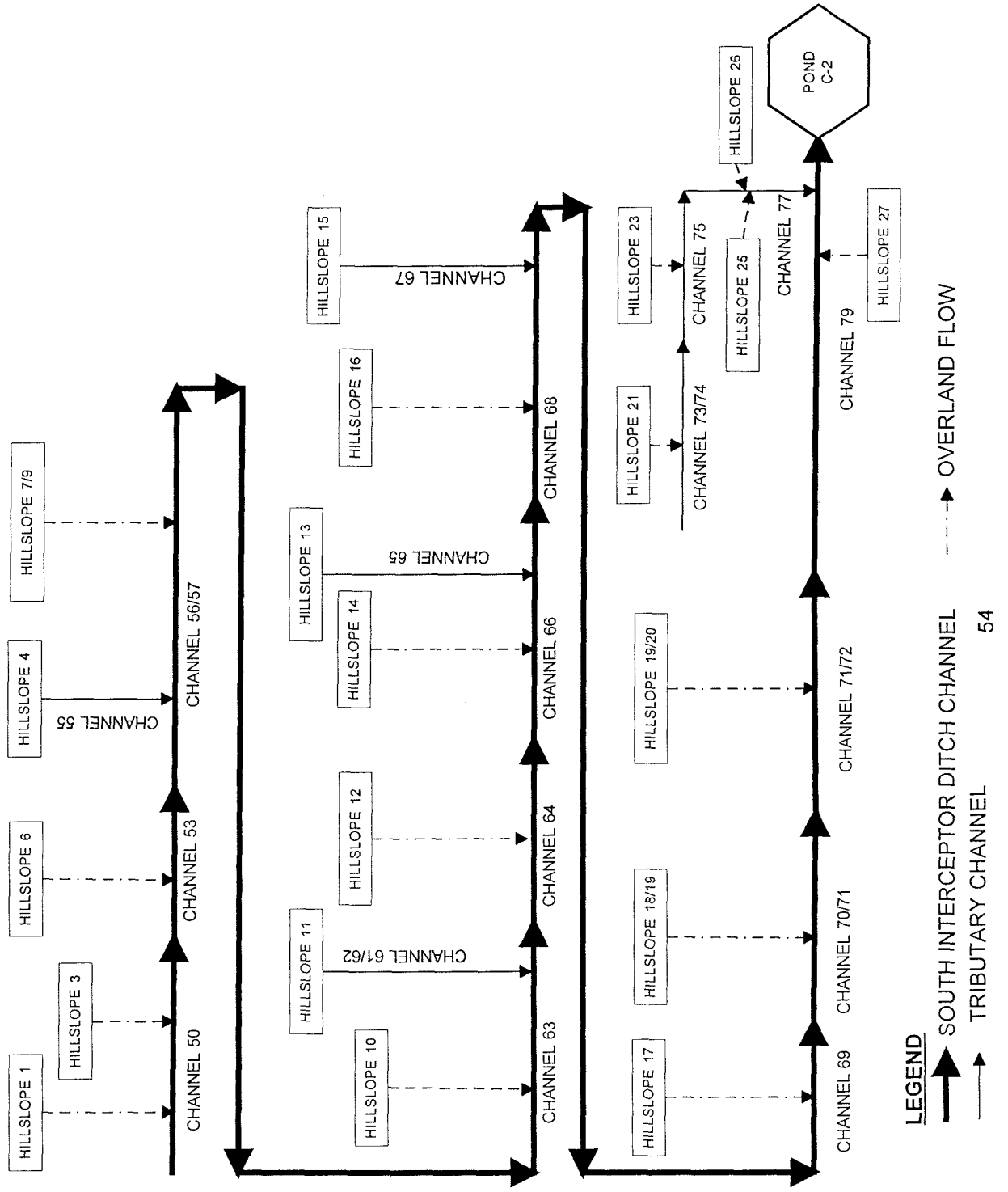
C.1.2 Watershed Routing

Surface runoff in the SID watershed generally flows from north to south down the hillslopes and channels to the SID which route the flow from west to east and terminate in Pond C-2. An eastern tributary of the SID that begins on the East Access Road (Hillslope 21), starts with runoff traveling from west to east and then south by southwest down channels 74, 75, and 76 (Appendix Figure C-1). The watershed routing diagram for the SID model is shown in Appendix Figure C-2.

C.1.3 Overland Flow Elements

The hillslopes, channels, and impoundments were mapped on 1:3,600 scale mapping using Arc-Info GIS. The hillslope map (Appendix Figure C-1) was printed on acetate and overlaid onto printed soil (Appendix Figure C-3) and vegetation (Appendix Figure C-4) maps of the same scale. OFEs were

Figure C-2.-- Routing Diagram for WEPP Model of the South Interceptor Ditch



Appendix Table C-1. Hillslope and Overland Flow Element Dimensions, Habitats, and Soils for the WEPP Model for the South Interceptor Ditch Watershed.

Hillslope Number	Area (m ²)	Habitat Type	Surface / Soil Type	OFE Width (m)	OFE Length (m)	Hillslope Length (m)
1	27,083	Mesic Mixed Grassland	Flatirons cobbly sandy loam (0 - 3%)	479	57	111
1	13,416	Mesic Mixed Grassland	Nederland very cobbly sandy loam (15 - 50%)	479	28	
1	12,458	Disturbed and Developed Areas	Denver-Kutch-Midway clay loam	479	26	
3	35,433	Paved Areas	Buildings, Pavement, and Other Impervious	279	127	155
3	7,812	Improved Gravel Road	Flatirons cobbly sandy loam (0 - 3%)	279	28	
4	1,042	Paved Areas	Buildings, Pavement, and Other Impervious	79	13	262
4	19,622	Improved Gravel Road	Flatirons cobbly sandy loam (0 - 3%)	79	249	
6	546	Improved Gravel Road	Denver-Kutch-Midway clay loam & Gravel	6	87	87
7 / 9	2,681	Disturbed and Developed Areas	Flatirons cobbly sandy loam (0 - 3%)	383	7	108
7 / 9	8,043	Reclaimed Mixed Grassland	Nederland very cobbly sandy loam (15 - 50%)	383	21	
7 / 9	1,532	Tall Marsh	Denver-Kutch-Midway clay loam	383	4	
7 / 9	11,873	Reclaimed Mixed Grassland	Denver-Kutch-Midway clay loam	383	31	
7 / 9	17,235	Annual Grass and Forbs	Denver-Kutch-Midway clay loam	383	45	
10	25,983	Paved Areas	Denver-Kutch-Midway clay loam	102	255	525
10	17,199	Disturbed and Developed Areas	Denver-Kutch-Midway clay loam	102	169	
10	3,366	Reclaimed Mixed Grassland	Denver-Kutch-Midway clay loam	102	33	
10	3,468	Disturbed and Developed Areas	Denver-Kutch-Midway clay loam	102	34	
10	510	Reclaimed Mixed Grassland	Denver-Kutch-Midway clay loam	102	5	
10	3,060	Annual Grass and Forbs	Denver-Kutch-Midway clay loam	102	30	
11	1,704	Improved Gravel Road	Denver-Kutch-Midway clay loam	6	284	284
12	1,297	Reclaimed Mixed Grassland	Flatirons and Nederland Series	34	38	250
12	5,257	Reclaimed Mixed Grassland	Denver-Kutch-Midway clay loam	34	154	
12	478	Disturbed and Developed Areas	Denver-Kutch-Midway clay loam	34	14	

Appendix Table C-1. Hillslope and Overland Flow Element Dimensions, Habitats, and Soils for the WEPP Model for the South Interceptor Ditch Watershed.

Hillslope Number	Area (m ²)	Habitat Type	Surface / Soil Type	OFE Width (m)	OFE Length (m)	Hillslope Length (m)
12	444	Reclaimed Mixed Grassland	Denver-Kutch-Midway clay loam	34	13	
12	1,058	Annual Grass and Forbs	Forb Community	34	31	
13	12,916	Reclaimed Mixed Grassland	Flatirons cobbly sandy loam (0 - 3%)	286	45	128
13	18,106	Reclaimed Mixed Grassland	Denver-Kutch-Midway clay loam	286	63	
13	2,875	881 Reclaimed Grassland	Denver-Kutch-Midway clay loam	286	10	
13	2,673	Disturbed and Developed Areas	Denver-Kutch-Midway clay loam	286	9	
14	3,188	Disturbed and Developed Areas	Denver-Kutch-Midway clay loam & Gravel	286	11	75
14	18,223	Annual Grass	Forb Community	286	64	
15	3,066	Paved Areas	Flatirons cobbly sandy loam (0 - 3%)	306	10	171
15	27,459	Reclaimed Mixed Grassland	Flatirons cobbly sandy loam (0 - 3%)	306	90	
15	4,574	Disturbed and Developed Areas	Flatirons cobbly sandy loam (0 - 3%) & Gravel	306	15	
15	13,874	Reclaimed Mixed Grassland	Nederland very cobbly sandy loam (15 - 50%)	306	45	
15	3,429	Disturbed and Developed Areas	Denver-Kutch-Midway clay loam	306	11	
16	2,758	Disturbed and Developed Areas	Denver-Kutch-Midway clay loam	306	9	135
16	38,520	Mesic Mixed Grassland	Denver-Kutch-Midway clay loam	306	126	
17	622	Improved Gravel Road	Denver-Kutch-Midway clay loam & Gravel	9	68	211
17	1,309	881 Reclaimed Grassland	Denver-Kutch-Midway clay loam	9	143	
18 / 19	14,282	Reclaimed Mixed Grassland	Flatirons cobbly sandy loam (0 - 3%)	386	37	260
18 / 19	1,544	Disturbed and Developed Areas	Concrete, Asphalt, Aggregate	386	4	
18 / 19	5,790	Reclaimed Mixed Grassland	Nederland very cobbly sandy loam (15 - 50%)	386	15	
18 / 19	3,474	Disturbed and Developed Areas	Denver-Kutch-Midway clay loam	386	9	
18 / 19	15,440	Reclaimed Mixed Grassland	Denver-Kutch-Midway clay loam & Gravel	386	40	
18 / 19	54,812	Mesic Mixed Grassland	Nederland very cobbly sandy loam (15 - 50%)	386	142	
18 / 19	772	Disturbed and Developed Areas	Denver-Kutch-Midway clay loam	386	2	

Appendix Table C-1. Hillslope and Overland Flow Element Dimensions, Habitats, and Soils for the WEPP Model for the South Interceptor Ditch Watershed.

Hillslope Number	Area (m ²)	Habitat Type	Surface / Soil Type	OFE Width (m)	OFE Length (m)	Hillslope Length (m)
18 / 19	4,246	Reclaimed Mixed Grassland	Denver-Kutch-Midway clay loam & Gravel	386	11	
19 / 20	31,122	Reclaimed Mixed Grassland	Flatirons and Nederland Series	273	114	296
19 / 20	17,199	Reclaimed Mixed Grassland	Denver-Kutch-Midway clay loam	273	63	
19 / 20	25,935	Mesic Mixed Grassland	Denver-Kutch-Midway clay loam	273	95	
19 / 20	546	Disturbed and Developed Areas	Denver-Kutch-Midway clay loam	273	2	
19 / 20	6,006	Mesic Mixed Grassland	Denver-Kutch-Midway clay loam	273	22	
21	6,147	Paved Areas	Pavement and Other Impervious	607	10	10
23	16,440	Reclaimed Mixed Grassland	Flatirons and Nederland Series	274	60	85
23	4,658	Reclaimed Mixed Grassland	Denver-Kutch-Midway clay loam	274	17	
23	2,192	Mesic Mixed Grassland	Denver-Kutch-Midway clay loam	274	8	
25	6,408	Mesic Mixed Grassland	Denver-Kutch-Midway clay loam	178	36	36
26	9,412	Mesic Mixed Grassland	Denver-Kutch-Midway clay loam	178	53	53
27	507	Mesic Mixed Grassland	Denver-Kutch-Midway clay loam & Gravel	30	17	30

delineated on the hillslope map using boundaries between soil series and vegetation habitats displayed on the soil and vegetation maps. Thus, changes in vegetation or soil type were used to define the OFE boundaries. Finally, the OFEs were digitized into GIS coverages.

The dimensions and slopes of the OFEs were determined using GIS. The WEPP watershed module requires that the hillslope must have a width equal to the length of the adjacent receiving channel. Hillslope widths were set to the adjacent channel length to be consistent with the WEPP watershed module, which was planned to be used to route the erosional material through the SID. Then the area of each OFE was determined using GIS. The overland flow length for each OFE was calculated by dividing the OFE area by the hillslope width as shown below.

$$\text{OFE Length} = \text{OFE Area} / \text{Adjacent Channel Length (i.e. Hillslope Width)}$$

The slope of each OFE was determined using GIS. First, one or more linear transects were drawn from the top to the bottom of each OFE on 2-foot contour interval mapping such that the transects visually represented the overall topography of the OFEs. The transects were drawn by hand in Arc-Info. Next, GIS was used to provide several slope values at points on the transects. The transect slope values were averaged by OFE to provide data that describes the average land surface profile in each OFE. Hillslope and OFE dimensions, soil types, and vegetation / habitat types are listed in Table C-1. The slope data for the OFEs and channel elements are shown in Tables C-2 and C-3. A map of the OFEs for the SID watershed is shown in Appendix Figure-5.

Data for the SID channel dimensions and slopes were obtained from the SID Characterization Study (EG&G, 1992). For this study, the rip-rap energy dispersion structures in the SID were ignored because the model would predicted unrealistic erosion of the structures. These structures, in affect, reduce the slope of the energy grade of the SID flow, which is analogous to reducing the slope of the channel. Therefore, ignoring these structures and their steep slopes was justified.

C.1.4 Soil Types

The soil series displayed on Appendix Figure C-3 are described and mapped by the Soil Conservation Service (SCS, 1980). It was determined that three general soil types, top-slope, side-slope and bottom-slope, would represent the Site soil series. Specific soil parameters were then determined and WEPP input soil files were created. Soil input files were also created to represent runoff and erosion

characteristics of paved surfaces, improved roads, and unimproved roads. A summary description of the soil types is given in Table C-4. The WEPP input data for each soil type are shown in Table C-5.

Table C-2. Slope Data for Overland Flow Elements (OFEs) for the
WEPP Model of the South Interceptor Ditch Watershed.

Hillslope Identifier	Number of OFEs	Hillslope Aspect (Degrees from North)	Hillslope Width (m)	Overland Flow Element Number / Length (m)	Percent OFE Length From Top	Land Surface Slope (m/m)
1	3	180	479	1 / 57	0%	0.146
					50%	0.193
					100%	0.224
				2 / 28	0%	0.241
					33%	0.300
					67%	0.211
				3 / 26	100%	0.240
					0%	0.240
					33%	0.235
					67%	0.187
					100%	0.106
3	2	180	279	1 / 127	0%	0.005
					100%	0.005
				2 / 28	0%	0.017
					25%	0.061
					50%	0.025
					75%	0.034
					100%	0.038
4	2	180	79	1 / 13	0%	0.005
					100%	0.005
				2 / 249	0%	0.018
					25%	0.024
					50%	0.025
					75%	0.040
					100%	0.132

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Hillslope Identifier	Number of OFEs	Hillslope Aspect (Degrees from North)	Hillslope Width (m)	Overland Flow Element Number / Length (m)	Percent OFE Length From Top	Land Surface Slope (m/m)
6	1	180	6	1 / 87	0%	0.088
					10%	0.195
					20%	0.194
					30%	0.186
					40%	0.129
					50%	0.106
					60%	0.101
					70%	0.131
					80%	0.157
					90%	0.162
					100%	0.110
7 / 9	5	180	383	1 / 7	0%	0.238
					50%	0.221
					100%	0.238
				2 / 21	0%	0.238
					25%	0.221
					50%	0.175
					75%	0.123
					100%	0.115
				3 / 4	0%	0.132
					25%	0.110
					50%	0.125
					75%	0.110
					100%	0.122
				4 / 31	0%	0.122
					25%	0.131
					50%	0.152
					75%	0.133
					100%	0.149
				5 / 45	0%	0.149
					25%	0.149
					50%	0.091
					75%	0.091
					100%	0.070

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10	6	180	102	1 / 255	0%	0.005
					100%	0.005
				2 / 169	0%	0.054
					33%	0.119
					67%	0.127
					100%	0.097
				3 / 33	0%	0.090
					10%	0.131
					20%	0.133
					30%	0.146
					40%	0.054
					50%	0.054
					60%	0.076
					70%	0.083
					80%	0.114
					100%	0.130
				4 / 34	0%	0.130
					25%	0.170
					50%	0.155
					75%	0.077
					100%	0.079
				5 / 5	0%	0.079
					50%	0.083
				6 / 30	100%	0.090
					0%	0.090
					25%	0.081
					50%	0.124
					75%	0.135
					100%	0.115

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Hillslope Identifier	Number of OFEs	Hillslope Aspect (Degrees from North)	Hillslope Width (m)	Overland Flow Element Number / Length (m)	Percent OFE Length From Top	Land Surface Slope (m/m)
11	1	180	6	1 / 284	0%	0.000
					10%	0.118
					20%	0.135
					30%	0.155
					40%	0.130
					50%	0.077
					60%	0.077
					70%	0.000
					80%	0.061
					90%	0.061
					100%	0.125
12	5	180	34	1 / 38	0%	0.000
					25%	0.117
					50%	0.147
					60%	0.173
					80%	0.107
				2 / 154	100%	0.072
					0%	0.072
					25%	0.091
					50%	0.199
					75%	0.162
				3 / 14	100%	0.105
					0%	0.105
					50%	0.105
				4 / 13	100%	0.104
					0%	0.104
					25%	0.097
					50%	0.095
				5 / 31	75%	0.093
					100%	0.125
					0%	0.125
					25%	0.134
					50%	0.130
					75%	0.122
					100%	0.114

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13	5	180	286	1 / 45	0%	0.062
					20%	0.084
					40%	0.168
					60%	0.219
					75%	0.228
					80%	0.250
					100%	0.178
				2 / 63	0%	0.178
					25%	0.132
					50%	0.181
					75%	0.138
					100%	0.115
				3 / 10	0%	0.115
					50%	0.114
14	2	180	286	1 / 11	100%	0.117
					0%	0.117
					50%	0.127
				4 / 9	100%	0.126
					0%	0.126
14	2	180	286	1 / 11	0%	0.130
					50%	0.143
					100%	0.148
				2 / 64	0%	0.148
					25%	0.174
					50%	0.182
					75%	0.185
					100%	0.193

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15	5	180	306	1 / 10	0%	0.003
					100%	0.821
				2 / 90	0%	0.821
					10%	0.036
					20%	0.060
					30%	0.195
					40%	0.175
					50%	0.123
					60%	0.147
					70%	0.162
					80%	0.133
					100%	0.104
				3 / 15	0%	0.104
					25%	0.000
					50%	0.012
					75%	0.189
				4 / 45	100%	0.123
					0%	0.123
					25%	0.120
					50%	0.126
					75%	0.135
				5 / 11	100%	0.114
					0%	0.114
					100%	0.116
16	2	180	306	1 / 9	0%	0.132
					50%	0.136
					100%	0.145
				2 / 126	0%	0.145
					25%	0.170
					50%	0.178
					75%	0.188
					95%	0.268
					100%	0.246

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17	2	180	9	1 / 68	0%	0.091
					50%	0.096
					100%	0.130
				2 / 143	0%	0.130
					50%	0.161
					100%	0.152
18 / 19	8	180	386	1 / 37	0%	0.007
					10%	0.023
					20%	0.012
					30%	0.029
					40%	0.207
					50%	0.268
					60%	0.306
					75%	0.297
					90%	0.200
					100%	0.130
				2 / 4	0%	0.130
					100%	0.137
				3 / 15	0%	0.137
					10%	0.203
					20%	0.155
					30%	0.155
					40%	0.165
					50%	0.121
					60%	0.097
					70%	0.070
					80%	0.072
					100%	0.061
				4 / 9	0%	0.061
					50%	0.059
					100%	0.038
				5 / 40	0%	0.038
					5%	0.059
					25%	0.154
					50%	0.166
					75%	0.155
					100%	0.192

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Hillslope Identifier	Number of OFEs	Hillslope Aspect (Degrees from North)	Hillslope Width (m)	Overland Flow Element Number / Length (m)	Percent OFE Length From Top	Land Surface Slope (m/m)
18 / 19				6 / 142	0%	0.192
					25%	0.121
					50%	0.133
					75%	0.145
					100%	0.192
				7 / 2	0%	0.192
					100%	0.020
				8 / 11	0%	0.020
					5%	0.192
					25%	0.174
					50%	0.160
					75%	0.100
					100%	0.100
19 / 20	5	175	273	1 / 114	0%	0.015
					20%	0.171
					30%	0.331
					45%	0.099
					60%	0.084
					75%	0.052
					85%	0.172
					100%	0.101
				2 / 63	0%	0.101
					25%	0.149
					50%	0.172
					75%	0.120
					100%	0.207
				3 / 95	10%	0.207
					20%	0.238
					60%	0.214
					80%	0.172
					100%	0.140
				4 / 2	0%	0.140
					100%	0.020
				5 / 22	0%	0.020
					5%	0.142
					25%	0.137
					50%	0.109
					100%	0.098

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Hillslope Identifier	Number of OFEs	Hillslope Aspect (Degrees from North)	Hillslope Width (m)	Overland Flow Element Number / Length (m)	Percent OFE Length From Top	Land Surface Slope (m/m)
21	1	180	607	1 / 10	0% 100%	0.050 0.050
23	3	120	274	1 / 60 2 / 17 3 / 8	0% 10% 25% 30% 50% 60% 70% 80% 90% 100% 0% 25% 50% 75% 100% 0% 50% 100%	0.036 0.048 0.133 0.182 0.289 0.289 0.179 0.185 0.240 0.289 0.289 0.283 0.248 0.195 0.173 0.173 0.110 0.092
25	1	120	178	1 / 36	0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%	0.135 0.106 0.131 0.187 0.231 0.165 0.130 0.184 0.184 0.083 0.113

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Hillslope Identifier	Number of OFEs	Hillslope Aspect (Degrees from North)	Hillslope Width (m)	Overland Flow Element Number / Length (m)	Percent OFE Length From Top	Land Surface Slope (m/m)
26	1	190	178	1 / 53	0%	0.110
					10%	0.106
					20%	0.119
					30%	0.221
					40%	0.214
					50%	0.217
					60%	0.186
					70%	0.172
					80%	0.108
27	1	190	30	1 / 17	0%	0.149
					25%	0.189
					50%	0.149
					75%	0.189
					100%	0.218

Table C-3. Channel Data for the SID Watershed.

Channel Identifier	Channel Aspect (Degrees from North)	Channel Width (m)	Channel Number / Length (m)	Percent Channel Length From Upstream End	Channel Slope (m/m)
50	90	5	472	0.0%	0.001
				8.0%	0.001
				8.5%	0.200
				12.0%	0.200
				12.5%	0.001
				19.3%	0.001
				21.0%	0.000
				26.0%	0.000
				27.8%	0.000
				30.9%	0.000
				31.0%	0.050
				43.0%	0.050
				43.5%	0.015
				64.5%	0.015
				100.0%	0.004

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Channel Identifier	Channel Aspect (Degrees from North)	Channel Width (m)	Channel Number / Length (m)	Percent Channel Length From Upstream End	Channel Slope (m/m)
53	90	3	6	0% 100%	0.035 0.065
54	120	0.9	290	0.0% 70.0% 100.0%	0.060 0.060 0.000
55	90	2	117	0% 100%	0.135 0.135
56 / 57	90	5	213	0.0% 29.0% 30.0% 56.0% 57.0% 61.0% 71.0% 74.0% 100.0%	0.050 0.010 0.004 0.004 0.150 0.000 0.000 0.020 0.020
60-61-62	183	2	126	0.0% 33.0% 35.0% 37.0% 80.0% 81.0% 100.0%	0.085 0.085 0.005 0.000 0.000 0.053 0.053
63	89	4	160	0.0% 18.0% 18.5% 41.6% 46.0% 100.0%	0.080 0.080 0.010 0.010 0.015 0.015
64	89	5	30	0.0% 34.0% 100.0%	0.015 0.010 0.010
65	175	1	102	0% 100%	0.162 0.162

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Channel Identifier	Channel Aspect (Degrees from North)	Channel Width (m)	Channel Number / Length (m)	Percent Channel Length From Upstream End	Channel Slope (m/m)
66	89	1	286	0.0%	0.006
				14.5%	0.006
				20.0%	0.030
				30.0%	0.030
				34.0%	0.000
				63.5%	0.000
				69.0%	0.004
				96.9%	0.004
				100.0%	0.000
67	180	1	175	0%	0.141
				100%	0.141
68	90	5	335	0.0%	0.000
				31.0%	0.005
				45.5%	0.005
				46.0%	0.000
				50.0%	0.000
				62.0%	0.000
				65.0%	0.015
				100.0%	0.015
69	90	3	9	0.0%	0.129
				90.0%	0.129
				100.0%	0.000
70 / 71	90	5	386	0.0%	0.003
				29.0%	0.005
				49.0%	0.001
				100.0%	0.000
71 / 72	90	8	273	0.0%	0.001
				22.0%	0.001
				59.0%	0.020
				68.0%	0.001
				100.0%	0.001
73	90	3	607	0.0%	0.011
				100.0%	0.016

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Channel Identifier	Channel Aspect (Degrees from North)	Channel Width (m)	Channel Number / Length (m)	Percent Channel Length From Upstream End	Channel Slope (m/m)
74	175	8	251	0.0%	0.016
				59.0%	0.026
				75.0%	0.078
				100.0%	0.051
75	274	3	263	0.0%	0.051
				100.0%	0.051
77	175	2	178	0.0%	0.120
				25.0%	0.120
				50.0%	0.180
				75.0%	0.140
79	175	8	30	100.0%	0.120
				0.0%	0.000
				20.0%	0.000
				51.0%	0.013
				100.0%	0.013

Table C-4. Description of Soils Used in WEPP Soil Input Files.

WEPP Soil File Name	Description
TOPSLOPE	Soils at top of landscape profile: Flatirons and Nederland Series
SIDESLOPE	Soils on sideslope of landscape profile: Denver-Kutch-Midway, Denver, Englewood, Leyden-Primen-Standley, Nunn series
BOTTOM	Soils at bottom of landscape profile: Englewood, Haverson, Nunn, Standley-Nunn, Valmont series
PAVEMENT	Parameters assumed based on output for runoff and erosion for impervious surfaces. Pavement soil file is used for asphalt, concrete, and buildings.
UNPAVED	Parameters assumed based on output for runoff and erosion for improved gravel roads and like disturbed areas. Pavement soil file is used for asphalt, concrete, and buildings.

Appendix Table C-5. Soil Input Data for RFETS Soils for the WEPP Model.

WEPP Soil File Name	Texture	Layers	Soil Albedo ¹	Initial Saturation ¹ (mm)	Inter-Rill Erodibility (kg*s/m ⁴)	Rill Erodibility (s/m)	Critical Shear Force (N/m ²)	Effective Hydraulic Conductivity (mm/hr)	Layer Thick- ness (mm)	Sand (% By Mass)	Clay (% By Mass)	Organic Matter (% By Volume)	Cation Exchange Capacity (meq/100g)	Rock Fragments ¹ (% By Volume)
TOPSLOPE Layer 1 Layer 2	V. Cobbly Sandy Loam	2	0.2	0.7	54,000	0.000347	1.5	26	150 650 - 1,200	63 25 - 49	19 31 - 75	6 0.2	22.5 25	60 55
SIDESLOPE Layer 1 Layer 2	Clay Loam	2	0.2	0.7	270,000	0.000598	1.5	12	200 1,050 - 1,330	43 20	34 60	4.9 0.1	28.3 26.2 - 29	10 10
BOTTOM Layer 1 Layer 2	Clay Loam	2	0.2	0.7	369,000	0.000506	1.5	12	160 875	44 34	28 40	4.5 0.3	24.6 29	10 10
PAVEMENT Layer 1 Layer 2	Clay	2	0.25	0.99	5	0.0001	20	0.0001 - 4	1,200 1050 - 1360	0 25	99 75	0.1 2	10 5	95 50
BUILDINGS Layer 1 Layer 2 Layer 3	Clay	3	0.25	0.99	9	0.0015	0.5	4	20 1,220 3620	2 0 0.9	3.8 99 99	85 0.1 0.1	5 10 10	10 95 95
UNPAVED Layer 1 Layer 2	Sandy Loam	1	0.25	0.75	10	0.0001	10	0.03 - 5	330 490	50.3 18-25	48.9 75	0.1 0.1	5 5-17	65 45 - 50
SID MAIN CHANNEL Layer 1 Layer 2	Clay	2	0.2	1.0	100	0.00001	10	3	100 1150	5 25	95 75	10 2	1 5	100 90

¹Data for Topslope, Sideslope, and Bottom soils are from Soils Survey of Golden Area, Colorado, USDA, NRCS.

Notes: 1) WEPP did not automatically adjust hydraulic conductivity. 2) Albedo assumed at 0.2.3) Initial saturation assumed at 0.7. 3) Tc was minimized at 1.5 for Soils.

Table C-6. Means and Standard Deviations of RFETS Surface Soil Data Grouped by Landscape Location.

Soil Location	Statistics	Sand %	Clay %	Conductivity ¹ mm/hr K(y=15cm)	Bulk Density g/cm ²	Organic Matter %	CEC meq/100g
Top-slope	Mean	63.2	18.5	116.3	1.15	6.0	22.5
	Stdev	12.4	7.3	76.9	0.23	1.0	5.8
	CV ²	19.6	39.5	66.1	20.0	16.7	25.8
Side-slope	Mean	46.3	27.2	35.2	1.13	5.7	25.0
	Stdev	12.4	9.8	25.9	0.23	2.0	5.4
	CV	26.8	36.0	73.6	20.4	35.1	21.6
Bottom-slope	Mean	44.4	28.3	31.0	1.39	4.5	24.6
	Stdev	16.8	12.0	19.2	0.27	1.7	7.2
	CV	37.8	42.4	61.9	19.4	13.8	29.3

¹ Hydraulic conductivity measured at a tension of 15 cm by a tension infiltrometer (Fedors and Warner, 1993).

² CV = Coefficient of Variation = (Mean/Standard Deviation)*100

An evaluation of the Site soil characteristics, including texture (percent sand, silt, and clay), hydraulic conductivity, bulk density, and percent organic matter determined that soil variability was so large that the most efficient method of grouping soils was by position on the landscape. Therefore, soils data were grouped into three categories: (1) Top-slope, which includes areas classified as the Flatirons series and the Nederland series; (2) Side-slope, which includes areas classified as the Denver-Kutch-Midway complex, the Leyden-Primen-Standley complex, the Willowman-Leyden association, and scattered areas of Engelman and Nunn series; and (3) Bottom-slope, which includes areas classified as Standley-Nunn association, Haverson, Nunn, Englewood, and Valmont series. These soil series exist adjacent to each other; grading from one to another. Soil data from the site indicated that variations in characteristics based on soil map delineations were so large that grouping soils by soil-series was not meaningful for modeling.

Table C-6 gives means and standard deviations for several soil characteristics, from Site-specific surface soil data, grouped by landscape position. The hydraulic conductivity data were taken from data collected by CSU in 1993 (Fedors and Werner, 1993). These data are mapped Appendix Figure C-6. The WEPP model runoff and erosion estimates are sensitive to soil hydraulic conductivity. The data show that there is a large difference in mean hydraulic conductivity between the soils on the top positions in the landscape and those on the side-slopes and at the slope base (bottom-slope). Although the standard deviations for hydraulic conductivity are very high for all soils positions, the coefficients of variation are quite similar for the three positions. These figures also compare well with those determined by Zika (1996) using a less comprehensive data set.

C.1.5 Vegetation and Cover

Site habitat types and their associated vegetation characteristics are mapped in Appendix Figure C-4. The data shown in Appendix Figure C-4 were provided by the Site Ecology Department. Many WEPP plant parameters were not measured in the field, but estimated values from data tables in the WEPP User Summary document were used for those parameters. Table C-7 describes the plant parameter values used in the model. Data sources for each parameter are given in Table C-7. Table C-8 lists the data input values for programming WEPP to the initial conditions of Site vegetation types at the start of the growing season.

A unique feature of WEPP is that it partitions runoff between rill and interrill areas, and it calculates shear stresses based on rill flow and rill hydraulics rather than sheet flow (Nearing et al, 1989). Rill areas are the areas between plants, and interrill areas, are the areas containing plants. Therefore, it was important to accurately reflect the numbers, spacing, and canopy cover of plants in the vegetation files. The Site-specific ecological monitoring data provided these parameters.

C.1.6 Climate Simulation

For this study, the Fort Collins, Colorado climate data, supplied with the WEPP model's climate data library, was used to generate a 100-year simulated climate using WEPP's CLIGEN module. The Fort Collins climate data were used by Zika (1996) to model runoff and erosion for research in Operable Unit Number 2 at the Site. Zika determined that the precipitation distribution for the Fort Collins data is similar to the precipitation distribution for the Site. Furthermore, the annual average precipitation for the Site and Fort Collins is nearly the same, and the two regions share similar geographic characteristics such as longitude and location relative to the Front Range.

The Fort Collins meteorological record (92 years) is more extensive than the Site's record (about 15 years). Therefore, the Fort Collins data should provide a better representation of extreme hydrologic events (e.g. 100-year return period storm). Site-specific data might be used for future simulations of individual years and specific storms.

Figure 1
Major Drainage Basins
at Rocky Flats

EXPLANATION

- Rock Creek
- Walnut Creek
- Woman Creek

Standard Map Features

- Buildings and other structures
- Solar evaporation ponds
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Contour (20-Foot)
- Rocky Flats boundary
- Paved roads
- Dirt roads

DATA SOURCE:
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data acquired by EG&G RSL, Las Vegas, NV. Contour data were derived from 1995 Topology (contours) were derived from digital elevation model (DEM) data by Morrison Knudsen (MK) using ESRI Arc TIN and LATICE to process the DEM data to create 5-foot contours. The DEM data was captured by the Remote Sensing Lab, Los Alamos National Laboratory, in 1987. The DEM post-processing performed by MK, Winter 1997.



Scale = 1 : 21330
1 inch represents approximately 1778 feet



State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

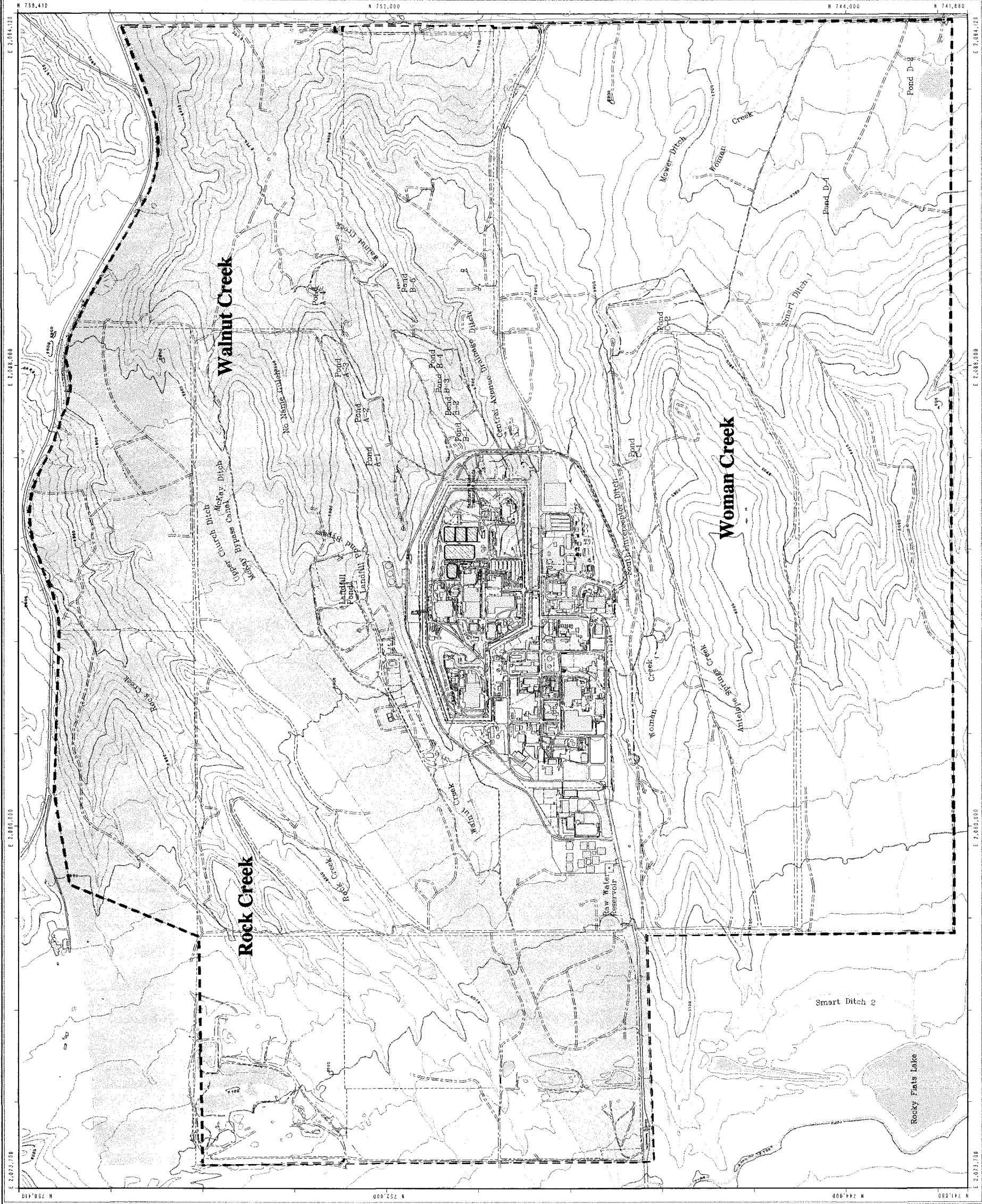
Prepared by:



Rocky Mountain
Remediation Services, L.L.C.
Geographic Information Systems Group
P.O. Box 1000
Golden, CO 80602-0001

MAP ID: 98-0178

October 15, 1998



Appendix B-1

EXPLANATION

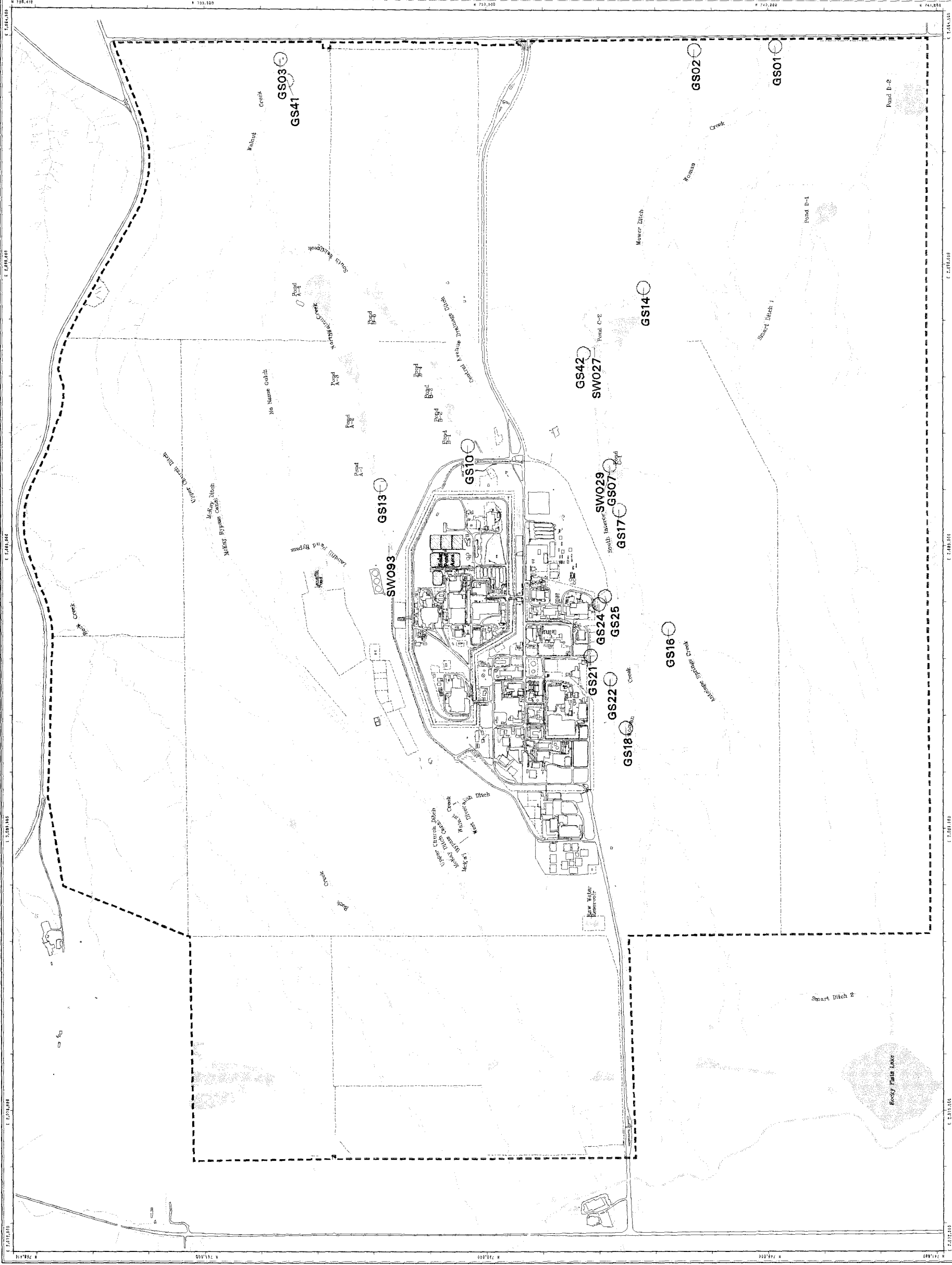
Monitoring Location

- Gaging Station

Standard Map Features

- Buildings and other structures
- Solar evaporation ponds
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Rocky Flats boundary
- Paved roads

DATA SOURCE: Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EGA's RSL, Las Vegas. Digitized from the orthophotographs. 1/95



Scale = 1 : 21330
1 inch represents approximately 1778 feet



State Plane Coordinates Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

Prepared by:

**Rocky Mountain
Remediation Services, LLC.**
Geographic Information Systems Group
Rocky Flats Environmental Technology Site
P.O. Box 404
Golden, CO 80602-0404

MAP ID: 98-0274-Q9-9W

October 18, 1995

Appendix C-6
Hydraulic Conductivity Locations
Sampled by CSU 1993

EXPLANATION

Sampling Features

Tension infiltrometer sampling location

Soils

- Denver clay loam, 2 - 5%
- Denver clay loam, 5 - 9%
- Denver-Kutch clay loam, 5 - 9%
- Denver-Kutch clay loam, 9 - 15%
- Denver-Kutch-Midway clay loam, 9 - 25%
- Englewood clay loam, 0 - 2%
- Englewood clay loam, 2 - 5%
- Flatirons cobbly sandy loam, 0 - 3%
- Flatirons stoney sandy loam, 0 - 5%
- Haverson loam, 0 - 3%
- Layden-Pitman-Standley cobbly clay loam, 15 - 60%
- McClave clay loam, 0 - 3%
- Midway clay loam, 9 - 30%
- Nederland very cobbly sandy loam, 15 - 60%
- Nunn clay loam, 0 - 2%
- Nunn clay loam, 2 - 5%
- Pits, gravel
- Rock outcrop, Sedimentary
- Standley-Nunn gravelly clay loam, 0 - 5%
- Valmont clay loam, 0 - 3%
- Valmont-Nederland very cobbly sandy loam, 0 - 3%
- Willowman-Layden cobbly loam, 8 - 30%
- Yoder Farmland-Midway complex, 15 - 60%

Standard Map Features

- Buildings and other structures
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Paved roads
- Dirt roads

DATA SOURCES
This data from the US Soil Conservation Service, National Engineering Laboratory, Denver, Colorado, was used to create this map. The data was digitized from the original maps and other sources. The data was not verified by the original source. The data was digitized from the original maps and other sources. The data was not verified by the original source.

Scale = 1:200,000
1 inch represents approximately 1600 feet

North Arrow

State Plane Coordinate System
Colorado North Zone
Datum: 1983

U.S. Department of Energy
Rocky Flats Environmental Technology Site

Prepared by:

Rocky Mountain

Remediation Services, L.L.C.
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2000 North Federal Avenue
Suite 200
Denver, CO 80202-4444

Map ID: 94-597427-801

October 20, 1994

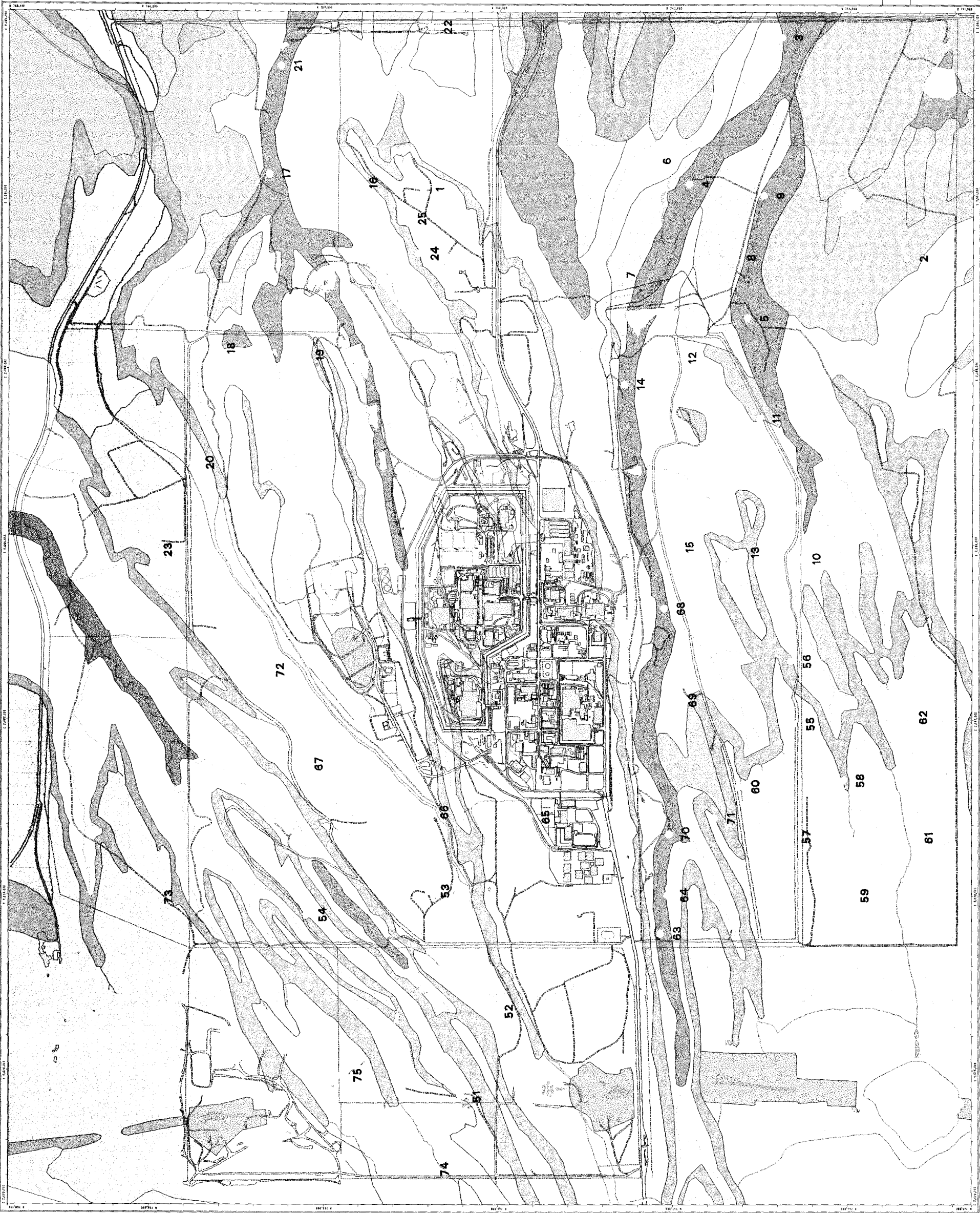


Table C-7. Input Data for Rocky Flats Environmental Technology Site Rangeland Habitats, Plant Management Files for the WEPP Model

WEPP Model Plant File Parameter Description		WEPP Parameter Code	Erosion Sensitivity of Parameter	Input Values For Rangeland Habitat Communities ¹														Comments		WEPP Code	Data Source
				XTGP	NEEDLE	MESIC	REGRASS	AGRASS	SMARSH	TMARSH	WETMEDW	881RECLM	IMPROAD	TOPROAD	SIDEROAD	PAVEMENT					
Change in surface residue mass coefficient, real - (aca)				2	2	2	2	2	2	2	2	2	5	2	2	2	5	No range of values provided. B. Elliot (USFS) used 2.09 in WEPP demonstration.	aca	Estimate	
Coefficient for leaf area index, real-(aleaf)				104	104	291	291	206	1078	1297	267	207	4	291	291	291	4	Community specific parameter - RFEITS Ecology Data	aleaf	TGD/Tab 8.4.3	
Change in root mass coefficient, real-(ar)				1.4	1.4	1.4	1.4	1.4	1.4	1.3	1.3	1.4	1.4	2	1.4	1.4	1.4	2 WEPP default for mixed grass prairie.	ar	WEPP *.plt files	
Parameter value for canopy height equation, real-(bbb)				4.8	4.8	4.8	4.8	4.8	4.8	3	4.8	23	1	4.8	4.8	4.8	1	1 WEPP default for mixed grass prairie.	bbb	WEPP *.plt files	
Daily removal of surface residue by insects, real-(bugs)				0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	1.3	0	0.0001	0.0001	0.0001	0	0 Assume 0.1 gram/m2-day loss due to insects and rodents	bugs	WEPP *.plt files	
Fraction of 1st peak of growing season, real-(cf1)				88	88	81	97	81	100	100	81	4.8	1	1	1	1	1	1 Based on assumption of using % cool season vs. warm season graminoid biomass values.	cf1	1994 EcMP data	
Fraction of 2nd peak of growing season, real-(cf2)				12	12	19	3	19	0	0	19	0.0001	0	0	0	0	0	0 Based on assumptions of using % cool season vs. warm season graminoid biomass values.	cf2	1994 EcMP data	
Carbon/Nitrogen ratio of residue and roots, real-(cn)				38	38	33	29	29	31	31	26	29	29	29	29	29	29	29 Table value for specific dominant species	cn	TGD/Tab 8.4.4	
Standing biomass where canopy cover is 100%, (kg/m2)/real-(cold)				0.176	0.176	0.132	0.1822	0.132	0.2924	0.7821	0.132	0.199	0.132	0.132	0.132	0.132	0.132	0 Calculated by multiplying the total biomass in the community by the factor needed to increase the actual total foliar cover to 100%.	cold	1994 EcMP data	
Frost free period, (days)/integer-(fip)				132	132	132	132	132	132	132	132	132	132	132	132	132	132	132 NOAA, Boulder Station - 90% probability	fip	NOAA	
Projected plant area coefficient for grasses, real-(gcoeff)				0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.1	0.43	0.43	0.43	0.43	0.1 Suggested in WEPP manual because not sensitive to soil loss	gcoeff	Default	
Average canopy diameter for grasses, (m)/real-(gdiam)				0.1	0.1	0.02	0.1	0.1	0.1	0.1	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01 Suggested in WEPP manual because not sensitive to soil loss.	gdiam	Default	
Average height for grasses (m), real-(ghgt)				0.35	0.35	0.33	0.32	0.3301	0.4	0.3	0.3301	0.3301	0.01	0.2	0.2	0.2	0.2	0.01 sampling. These heights include the flowering stalks.	ghgt	1994 EcMP data	
Average number of grasses along a 100m belt transect, real-(gpop)				3308	3308	4253	1701	1487	4096	421	4253	3150	1	50	50	50	10	1 Rocky Flats basal cover data.	gpop	1994 EcMP data	
Minimum temperature to initiate growth, (degrees C) real-(gttemp)				10	10	10	10	10	10	10	10	10	10	10	10	10	10	10 This varies by species, but estimated 10 Celsius for all habitats.	gttemp	WEPP *.plt files	
Maximum herbaceous plant height (m), real-(hmax)				0.5	0.5	0.5	0.5	0.5	0.6	2	0.6	0.25	0.01	0.2	0.2	0.2	0.2	0 Estimate based on experience in field. No data available for Rocky Flats.	hmax	Estimate	
Maximum standing live biomass, (kg/m2)/real-(plive)				0.1577	0.1577	0.12	0.1458	0.12	0.266	0.4444	0.12	0.178	0.01	0.03	0.03	0.03	0.03	0 Actual biomass from Rocky Flats ecological monitoring site.	plive	1994 EcMP data	
Plant drought tolerance factor, real-(ptol)				0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2 WEPP default for mixed grass prairie.	ptol	WEPP *.plt files	
Day of peak standing crop, 1st peak, (julian day) interger-(pscday)				176	176	176	176	176	176	176	176	176	176	176	176	176	176	176 Mid-late June. Used June 25.	pscday	Estimate	
Minimum amount of live biomass, (kg/m2)/real-(rgcmin)				0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0	0.01	0.01	0.01	0.01	0 WEPP default for short grass prairie.	rgcmin	WEPP *.plt files	
Root biomass in top 10cm, (kg/m2)/real-(root10)				0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.01	0.01	0.01	0.01	0.01	0.01 Table Value from WEPP User's Manual	root10	UM - Pg. 23	
Fraction of live and dead roots from maximum at start of year, real-(roof)				0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5 Provided in WEPP manual.	roof	Estimate	
Day on which peak occurs, 2nd growing season, (julian day), interger-(scday2)				247	247	247	247	247	0	0	247	247	0	0	0	0	0	0 Early Sept. Used Sept. 4.	scday2	Estimate	
Projected plant area coefficient for shrubs, real-(scoeff)				0.7	0.7	0.7	0	0	0	0.7	0.7	0.7	0	0	0	0	0	0 Suggested in WEPP manual because not sensitive to soil loss.	scoeff	Default	
Average canopy diameter for shrubs (m), real-(sdiam)				0.47	0.47	0.2	0	0	0	0	0.2	0.2	0	0	0	0	0	0 Estimate of average height at TR06. Never measured.	sdiam	Default	
Average height of shrubs (m), real-(shgt)				10	10	83	0	0	0	0	10	41	0	0	0	0	0	0 Based on a density of 0.11 stems/m ² at TR06 found about every 9 m.	shgt	Estimate	
Average number of shrubs along a 100m belt transect, real-(sgpop)				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0 No trees on grassland.	sgpop	Estimate	
Projected plant area coefficient for trees, real-(tcoeff)				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0 No trees on grassland.	tcoeff	Estimate	
Average canopy diameter for trees(m), real-(tdiam)				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0 No trees on grassland.	tdiam	Estimate	
Minimum temperature to initiate senescence, (degrees C)/real-(tempmn)				-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-2	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5 WEPP default for mixed grass prairie.	tempmn	WEPP *.plt files	
Average height for trees (m), real - (thgt)				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0 No trees on grassland.	thgt	Estimate	
Average number of trees along a 100m belt transect, real-(tpop)				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0 No trees on grassland.	tpop	Estimate	
Fraction of initial standing woody biomass (%), real-(wood)				0	0	0	0	0	0	0	0	1	0	0	0	0	0	0 No trees on grassland.	wood	Estimate	

¹ Key to Rocky Flats Environmental Technology Site Habitat Communities

Group Code	Habitat Description
XTGP	Xeric Tall Grass Prairie
NEEDLE	Xeric Needle-and-Threadgrass Prairie
MESIC	Mixed Mesic Grassland
REGRASS	Reclaimed Grassland
AGRASS	Annual Grass and Forb Community
SMARSH	Short Marsh
TMARSH	Tall Marsh
WETMEDW	Wet Meadow
881RECLM	Building 881 Reclaimed Grassland
IMPROAD	Improved Gravel Road
TOPROAD	Unimproved Road on Flatirons and Netherland Soils
SIDEROAD	Unimproved Road on Denver-Kutch Midway Clay Loam Soils
PAVEMENT	Paved Surfaces (e.g. Buildings, Roads, Parking Lots)

Table C-8. Input Data for Rocky Flats Environmental Technology Site Rangeland Habitats Initial Conditions Files for the WEPP Model.

WEPP Model Plant File Parameter Description		WEPP Parameter Code	Erosion Sensitivity of Parameter	Input Values For Rangeland Habitat Communities ¹												
				XTGP	NEEDLE	MESIC	REGRASS	AGRASS	SMARSH	TMARSH	WETMEDW	881RECLM	IMPROAD	TOPROAD	SIDEROAD	PAVEMENT
Initial frost depth (m), real-(frdp)		frdp	None	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Average rainfall during growing season (m), real-(pptg)		pptg	None	0.256	0.256	0.256	0.256	0.256	0.256	0.256	0.256	0.256	0.256	0.256	0.256	0.256
Initial residue mass above the ground (kg/m2), real-(rmagt)		rmagt	Moderate	0.057	0.07885	0.06	0.0729	0.0506	0.113	0.222	0.06	0.1782	0	0.015	0.015	0
Initial residue mass on the ground(kg/m2), real-(rmogt)		rmogt	Moderate	0.1115	0.1714	0.1125	0.1137	0.1036	0.226	0.444	0.1125	0.3564	0	0.025	0.025	0
Initial random roughness for rangeland (m), real-(rough)		rough	High	0.001	0.02	0.001	0.001	0.01	0.005	0.005	0.005	0.01	0.001	0.01	0.01	0.005
Initial snow depth (m), real-(snodpy)		snodpy	None	0	0	0	0	0	0	0	0	0	0	0	0	0.005
Initial depth of thaw (m), real-(thdp)		thdp	None	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0	0.01	0	0	0
Depth of secondary tillage layer (m), real -(tillay(1))		tillay(1)	None	0	0	0	0	0	0	0	0	0	0.01	0.001	0	0.01
Depth of primary tillage layer (m), real-(tillay(2))		tillay(2)	None	0	0	0	0	0	0	0	0	0	0	0	0	0
Interrill litter surface cover (0-1), real-(resi)		resi	High	0.612	0.734	0.75	0.75	0.544	0.623	0.645	0.553	0.74	0.25	0.15	0	0
Interrill rock surface cover (0-1), real-(roki)		roki	High	0.192	0.034	0.3	0.3	0.121	0.03	0.0016	0.14	0.03	0.25	0.25	0.15	0
Interrill basal surface cover (0-1), real-(basi)		basi	High	0.182	0.216	0.291	0.112	0.155	0.296	0.136	0.291	0.21	0	0.07	0.07	0
Interrill cryptogamic surface cover (0-1), real-(cryi)		cryi	High	0	0	0	0	0	0	0	0	0	0	0	0	0
Rill litter surface cover (0-1), real-(resr)		resr	High	0.612	0.734	0.553	0.704	0.544	0.623	0.645	0.553	0.74	0.25	0.15	0	0
Rill rock surface cover (0-1), real-(rokr)		rokr	High	0.192	0.034	0.14	0.133	0.121	0.03	0.0016	0.14	0.03	0.25	0.25	0.25	0
Rill basal surface cover (0-1), real-(basr)		basr	High	0.182	0.216	0.291	0.112	0.155	0.296	0.136	0.291	0.21	0	0.07	0.07	0
Rill cryptogamic surface cover (0-1), real-(cryr)		cryr	High	0	0	0	0	0	0	0	0	0	0	0	0	0
Total foliar (canopy) cover (0-1), real (cancov)		cancov	High	0.858	0.894	0.91	0.8	0.86	0.913	0.55	0.91	0.91	0	0.22	0.3	0

Key to Source Data for Rocky Flats Environmental Technology Site Vegetation			
Comments	Data Source	WEPP Code	
Estimated 1 cm initial frost depth.	Estimate	frdp	
Sum of monthly mean precipitation	AV-R-93-08-200	pptg	
Used 1/2 of the total annual biomass amount. Reclaimed grassland values used here.	1994 EcMP Data	rmagt	
Used 1/2 the measured litter value from site. Reclaimed grassland values used here.	1994 EcMP Data	rmogt	
Used average value for Akron and Meeker, CO - .02 = Xeric, .01 = Other, .005=Marsh	WEPP UM - Pg. 25	rough	
Start with no snow on ground.	Estimate	snodpy	
Estimated 1 cm initial thaw depth.	Estimate	thdp	
Suggested in manual for no tillage.	WEPP Default	tillay(1)	
Suggested in manual for no tillage.	WEPP Default	tillay(2)	
Assumed value. Roads have grass strip between tire ruts.	1994 EcMP Data	resi	
Assumed value. Roads have grass strip between tire ruts.	1994 EcMP Data	roki	
Assumed value. Roads have grass strip between tire ruts.	1994 EcMP Data	basi	
Assumed value. Roads have grass strip between tire ruts.	1994 EcMP Data	cryi	
Assumed value. Roads have grass strip between tire ruts.	1994 EcMP Data	resr	
Assumed value. Roads have grass strip between tire ruts.	1994 EcMP Data	rokr	
Assumed value. Roads have grass strip between tire ruts.	1994 EcMP Data	basr	
Assumed value. Roads have grass strip between tire ruts.	1994 EcMP Data	cryr	
Assumed value. Roads have grass strip between tire ruts.	1994 EcMP Data	cancov	

1 Key to Rocky Flats Environmental Technology Site Habitat Communities		
Group Code	Habitat Description	
XTGP	Xeric Tall Grass Prairie	
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IMPROAD	Improved Gravel Road	
TOPROAD	Unimproved Road on Flatirons and Nederland Soils	
SIDEROAD	Unimproved Road on Denver-Kutch Midway Clay Loam Soils	
PAVEMENT	Paved Surfaces (e.g. Buildings, Roads, Parking Lots)	



Appendix C-3 Soils Map

EXPLANATION

- Denver clay loam, 2 - 5%
- Denver clay loam, 5 - 9%
- Denver-Kitch clay loam, 5 - 9%
- Denver-Kitch clay loam, 9 - 15%
- Denver-Kitch-Midway clay loam, 9 - 20%
- Englewood clay loam, 0 - 2%
- Englewood clay loam, 2 - 5%
- Flattens cobbly sandy loam, 0 - 3%
- Flattens stoney sandy loam, 0 - 5%
- Haverton loam, 0 - 3%
- Layden-Princeton-Standley cobbly clay loam, 15 - 80%
- McClellan clay loam, 0 - 3%
- Midway clay loam, 9 - 30%
- Nearfield very cobbly sandy loam, 10 - 60%
- Nunn clay loam, 0 - 2%
- Nunn clay loam, 2 - 5%
- Pite gravel
- Rock outcrop, Sedimentary
- Standley-Nunn gravelly clay loam, 0 - 5%
- Valmont clay loam, 0 - 3%
- Valmont-Nearfield very cobbly sandy loam, 0 - 2%
- Willowman-Layden cobbly loam, 5 - 30%
- Yoe-Fairmont-Midway complex, 15 - 60%

Standard Map Features

- Buildings and other structures
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Paved roads
- Dirt roads

DATA SOURCES:
Derived from the US Soil Conservation Service
National Engineering Area Soil Survey - 1983
Derived from the US Soil Conservation Service
National Engineering Area Soil Survey - 1983
Derived from the US Soil Conservation Service
National Engineering Area Soil Survey - 1983
Derived from the US Soil Conservation Service
National Engineering Area Soil Survey - 1983
Derived from the US Soil Conservation Service
National Engineering Area Soil Survey - 1983

Scale = 1:50,000
1 inch represents approximately 400 feet
North Arrow
State Plane Coordinate System
Datum: NAD83

U.S. Department of Energy
Rocky Flats Environmental Technology Site

Prepared by:

RMRS





















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MAP ID: 98-001-001








October 26, 1999

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LEGEND

- | | |
|-----------------------------------------------------------------------------------|------------------------------------------|
|  | Riparian Woodland |
|  | Leopard Riparian Shrubland |
|  | Wet Meadow/WMarsh Ecotone |
|  | Short Upland Shrubland |
|  | Willow Riparian Shrubland |
|  | Annual Grass/Fork Community |
|  | Xeric Tallgrass Prairie |
|  | Pondosa Woodland |
|  | Reclaimed Mixed Grassland |
|  | Mesic Mixed Grassland |
|  | Savanna Shrubland |
|  | Tall Upland Shrubland |
|  | Short Marsh |
|  | Xeric Needle and Thread Grass |
|  | Short Grassland |
|  | Disturbed and Developed Areas |
|  | Open Water |
|  | Riparian, Rock, and Gravel Pile Mudflats |
|  | Tree Plantings |
|  | Tall Marsh |

Standardized Food Use

- | | |
|-----------------------------------------------------------------------------------|-----------------------------------------------------|
|  | Standard map features |
|  | Buildings and other structures |
|  | Lakes and ponds |
|  | Streams, ditches, or other drainage features |
|  | Fences and other barriers |
|  | Paved roads |
|  | Dirt roads |

DATA SOURCES
Vegetation map data provided by
ATI Environmental Services
Ecology Group.
Buildings, roads, hydrography, roads and other
structures from 1982 aerial fly-over data
captured by ES&S RS-1, Las Vegas.
Digitized from the orthorectification, 1/85

NOTE: This map does not show all Federally designated wetlands. See the 1995 Data wetlands map prepared by the U.S. Army Corps of Engineers for designated wetland basins.



Scale = 1:5000



State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

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proposed

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